[redacted]

Chapter 15
DAMAGE TO FOREST STANDS [redacted]

[redacted] INTRODUCTION [redacted]

[redacted] Forest stands may protect personnel from some effects of nuclear weapon explosions, for example, the direct effects of thermal radiation; however, the trees themselves are quite vulnerable to breaking, uprooting, and ignition. Falling limbs and trees may be a hazard, and the debris on the forest floor may impede troop and vehicle movement. In dry, windy weather a nuclear explosion may ignite forest fires, and the smoke and flame may extend the range of hazardous effects many times. The vulnerability of forests depends upon recent local weather history, and upon the type of tree stand involved.

[redacted] This chapter is divided into three sections. Section I provides data concerning air blast damage to various types of forest stands. Section II contains a discussion of the effects of tree blowdown on troop and vehicle movement and provides methods to predict the degree to which movement might be impaired as a result of tree blowdown. Section III provides information concerning the effects of thermal radiation on forests and the fire hazards that might arise therefrom.

SECTION I
[redacted] AIR BLAST [redacted]

15-1 Forest Stand Types [redacted]

[redacted] Forest stands may be divided into four general types for the purpose of discussing air blast effects. Types I through IV as well as the subtypes of Type IV are described in the following discussion.

TYPE I: IMPROVED NATURAL OR PLANTED CONIFER FORESTS OF EUROPEAN TYPE. Stands of this type generally occur in Western Europe. They either have been planted or are natural stands that have been cultivated. Characteristics of this type of forest include uniform tree spacing, uniform height and diameter, and a dense crown canopy. Low stumps usually will be found within the stand as a result of thinning. Lower limbs will be clear as a result of pruning, and there will be little or no underbrush. All of these characteristics combine to provide good visibility and easy passage through the forest. Damage to these stands generally is caused by breaking the trunks rather than by uprooting.

TYPE II. UNIMPROVED NATURAL CONIFER FORESTS THAT HAVE DEVELOPED UNDER UNFAVORABLE GROWING CONDITIONS. This type of forest is found in Western Europe and Southeast Asia. Random tree spacing, height, and diameter together with irregular crown canopy characterize this type of stand. The forest floor is partially covered with dead fallen trees, and where clearings occur there is usually heavy underbrush. Visibility is generally poor and passage through the forest is difficult. Damage usually results from uprooting rather than breaking.

TYPE III. UNIMPROVED NATURAL CONIFER FORESTS THAT HAVE DEVELOPED UNDER FAVORABLE GROWING CONDITIONS. This type of forest occurs in Western Europe and Southeast Asia. These forests are characterized by random tree spacing and diameter, uneven crown canopy, and irregular clearings. Visibility and passage through these stands are difficult in Western Europe, although the underbrush generally is light, since dead fallen trees clutter the forest floor.

[redacted]

[redacted] In Southeast Asia, dense shrub undergrowths usually cover the forest floor. Damage to this type of forest usually results from uprooting.

TYPE IV. ALL TYPES OF DECIDUOUS FORESTS. The trees in these stands are similar to the deciduous trees of Western Europe and Southeast Asia. Since damage to these trees depends on the condition of the foliage, two categories must be considered: IV (f) is category type IV with foliation, and IV (d) is type IV without foliation. In both cases extensive crown damage and breakage of limbs will occur. In most ground, trunk damage will be caused mainly by uprooting. This class of forests is broken down into four subtypes:

TYPE IVa. This subtype includes two further subtypes that have different characteristics but produce similar blowdown obstacles equidistant from a particular nuclear burst. Two categories are required as a result of the difference in time required to clear away blowdown obstacles.

TYPE IVa-1. This subtype occurs in Western Europe and Southeast Asia. It includes most temperate zone deciduous forests, such as the shorter, more open parts of the dry season deciduous forests of Northern Southeast Asia and the evergreen oak forests at elevations of 3,000 to 7,000 feet in Southeast Asia. The trees

Table 15-1 [redacted] Average Height of Trees, Diameter, Tree Density, and Length of Tree Stem [redacted]

Forest Stand Type	Tree Diameter	Average Height of Trees* (feet)	Average Tree Density per Acre*	Average Total Tree Stem-feet per Acre*
I	up to 24 in.	130	75	9,750
II	up to 20 in.	50	260	13,000
III	up to 40 in.	80	200	16,000
IVa†	up to 40 in.	80	200	16,000
IVa‡	24-in. average	100	140	14,000
IVb‡	40-in. average	100	850	85,000
IVc§	up to 18 in.	35	40	1,400
IVd	up to 18 in.	40	100	4,000

*[redacted] Stem-feet per acre is determined by multiplying average tree height by tree density.
†[redacted] Considers only trees 6 in. or larger in diameter.
‡[redacted] Height varies up to 200 ft in rain forest and up to 150 ft in dry season deciduous forest for about 10 percent of trees. Diameter varies up to 80 in. for 10 percent of rain forest trees and up to 60 in. for 10 percent of dry season deciduous forests.
§[redacted] Height varies from 10-50 ft.

[redacted]

of this subtype are defoliated in the winter in the temperate zone with the exceptions of the evergreen oak (not defoliated) and the dry season forests of Northern Southeast Asia, which are defoliated in the summer.

TYPE IVa-2. Teak plantations and the denser, taller cloud forests that occur at lower elevations are included in this type. The teak plantation trees are planted 15 to 20 feet apart and produce a continuous canopy when foliated. No foliation is present during the dry season. The cloud forests start at an elevation of about 3,500 feet on the mountain slopes of Southeast Asia. The canopy of these forests gives a matted appearance from the air.

TYPE IVb. This subtype includes rain forests of Southeast Asia and the majority of the dry season deciduous forests of Northern Southeast Asia. Although no data are available concerning attenuation of the air blast wave, it is probable that these forests are sufficiently dense to decrease the radius of blast effect, thereby reducing the damage distance of a nuclear explosion.

TYPE IVc. This type includes cloud forests at high elevations, savannas, and low open forests that are made up of small scattered trees. This type of forest, when defoliated, is a good approximation for open deciduous wooded areas, such as orchards, in temperate zones.

TYPE IVd. This type consists of rubber plantation trees that occur mainly in Southeast Asia. The characteristics include little underbrush and dense, overlapping crowns.

[redacted] Table 15-1 shows the characteristic dimensions, tree densities, and tree stem-feet per acre for the forest stand types described above.

Table 15-2 [redacted] Index of Isodamage Curves Showing Forest Stand Type and Applicable Figure Number for Indicated Degree of Damage [redacted]

Forest Stand Type	Light Damage	Moderate Damage	Severe Damage	Total Damage
I	NA	15- 2	15- 3	15- 4
II	NA	15- 5	15- 6	15- 7
III	NA	15- 8	15- 9	15-10
IVa-1(f)	*	15-11	15-12	15-13
IVa-1(d)	15-1	15-14	15-15	15-16
IVa-2(f)	*	15-17	15-18	15-19
IVa-2(d)	15-1	15-20	15-21	15-22
IVb(f)	*	15-23	15-24	15-25
IVb(d)	*	15-26	15-27	15-28
IVc(f)	*	15-29	†	15-30
IVc(d)	15-1	15-31	†	15-32
IVd	*	15-33	†	15-34

[redacted] The ground range for Light Damage, 50% branch breakage, is less than the ground range for Moderate Damage, 750 stem-feet down per acre.

[redacted] Forest is of insufficient density and/or height to produce 7,500 stem-feet down per acre.

15-2 Damage-Distance Relations [redacted]

[redacted] Isodamage curves that are functions of weapon yield, distance, and height-of-burst are shown in Figures 15-1 through 15-34 for the forest stand types described in paragraph 15-1. Table 15-2 provides an index of the figures as a function of forest stand type and degree of damage. The degrees of damage shown in Table 15-2 are defined as follows:

TOTAL DAMAGE: 90 percent or more of trees are uprooted.

[redacted]

[redacted] SEVERE DAMAGE: 9,000 feet of tree stem down per acre for coniferous forests and 7,000 feet of tree stem down per acre for deciduous forests.

MODERATE DAMAGE: 1,500 feet of tree stem down per acre for coniferous forests and 750 feet of tree stem down per acre for deciduous forests.

LIGHT DAMAGE: 50 percent breakage of crowns and branches for deciduous forests. Does not exist for coniferous forests.

[redacted]

[redacted]

Problem 15-1 Calculation of Air Blast Damage to Forest Stands

[redacted] Figures 15-1 through 15-34 show total, severe, moderate, and light isodamage curves for different types of forest stands. Definitions of the degrees of damage are provided in paragraph 15-2. Decreases in the damage distances for shallow subsurface bursts may be estimated from Figure 11-24 by the methods described in Problem 11-2.

[redacted] *Scaling.* For yields between those for which isodamage curves are provided, scale as follows:

$$\frac{d}{d_i} = \frac{h}{h_i} = \left(\frac{W}{W_i}\right)^{1/3}$$

where d_i and h_i are the distance from ground zero and the height of burst, respectively, for yield W_i, which is the nearest yield to the desired yield for which a curve is provided; and d and h are the corresponding distance and height of burst for a (desired) yield of W kt or Mt (W and W_i must be in the same units).

For yields greater than 10 Mt this scaling becomes

$$\frac{d}{d_{10}} = \frac{h}{h_{10}} = \frac{[W(Mt)]^{1/3}}{(10)^{1/3}} = \frac{[W(Mt)]^{1/3}}{2.15}$$

where d_{10} and h_{10} are the distance from ground zero and height of burst, respectively, for 10 Mt; and d and h are the corresponding distance and height of burst for a yield of W Mt.

[redacted] *Example* [redacted]

Given:

a. A 5 kt weapon burst at a height of 400 feet above a Type IVa-1(f) forest stand.

b. A 20 Mt weapon burst at a height of 1,000 feet above a Type I forest stand.

Find:

a. The distance to which severe damage extends for the Type IVa-1(f) forest stand.

b. The distance to which moderate damage extends for the Type I forest stand.

Solution:

a. Table 15-2 shows that Figure 15-12 contains the isodamage curves appropriate for a Type IVa-1(f) forest stand. Examination of Figure 15-12 shows that the yield nearest 5 kt for which an isodamage curve is provided is 3 kt. The corresponding height of burst for a 3 kt weapon is

$$h_3 = h\left(\frac{3}{W}\right)^{1/3} = 400 \times \left(\frac{3}{5}\right)^{1/3} = 340 \text{ ft.}$$

From Figure 15-12, at a height of burst of 340 feet, the distance from ground zero to which severe damage will occur to a Type IVa-1(f) forest stand is 3,000 feet.

b. Table 15-2 shows that Figure 15-2 contains isodamage curves appropriate for moderate damage to a Type I forest stand. The corresponding height of burst for a 10 Mt weapon is

$$h_{10} = \frac{2.15\ h}{(W)^{1/3}} = \frac{2.15 \times 1{,}000}{(20)^{1/3}} = 790 \text{ ft.}$$

From Figure 15-2, at a height of burst of 790 feet, the distance from ground zero to which moderate damage to a Type I forest stand occurs from a 10 Mt weapon is 42,000 feet.

Answer:

a. The corresponding distance for severe damage to a Type IVa-1(f) forest stand from a 5 kt weapon burst at a height of 400 feet is

$$d = d_3\left(\frac{W}{3}\right)^{1/3} = 3{,}000 \times \left(\frac{5}{3}\right)^{1/3} = 3{,}560 \text{ ft.}$$

b. The corresponding distance for moderate damage to a Type I forest stand from a 20 Mt

[redacted]

[redacted]

[redacted]

weapon at a height of 1,000 feet is

$$d = \frac{d_{10}[W(Mt)]^{1/3}}{2.15} = \frac{42{,}000 \times (20)^{1/3}}{2.15}$$

$$= 53{,}000 \text{ ft.}$$

Reliability: The curves of Figures 15-1 through 15-34 are based on observed results of limited full scale tests, limited high explosive field tests, and extensive laboratory experiments. No definite estimate of the reliability of the scaling for yields above about 30 Mt can be made.

Related Material: See paragraphs 15-1 and 15-2. See also Figure 11-24 and Problem 11-2.

[redacted]

[redacted]

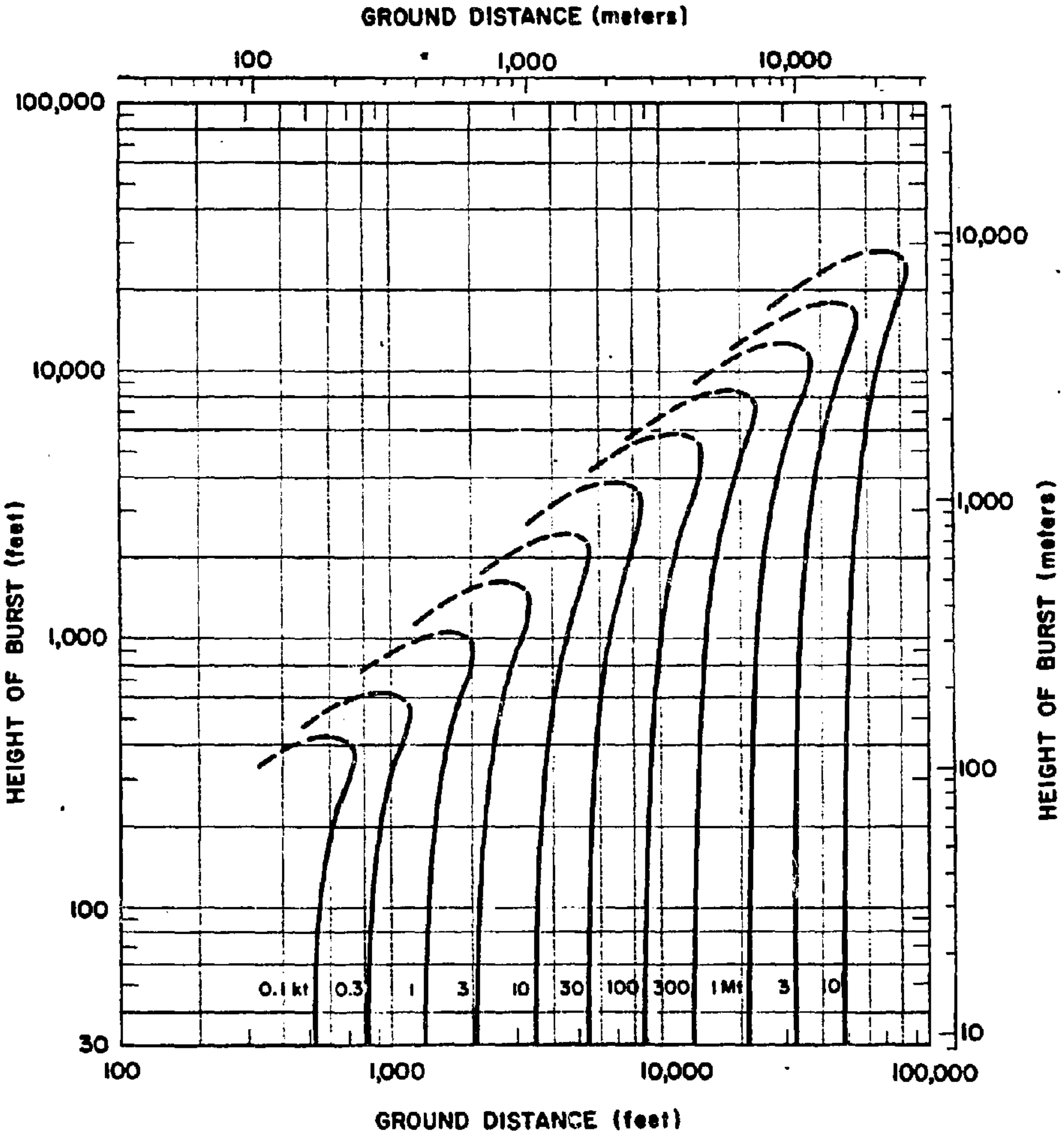

Figure 15-1. [redacted] Light Damage to Various Broadleaf Forest Types (see Table 15-2) [redacted]

[redacted]

[redacted]

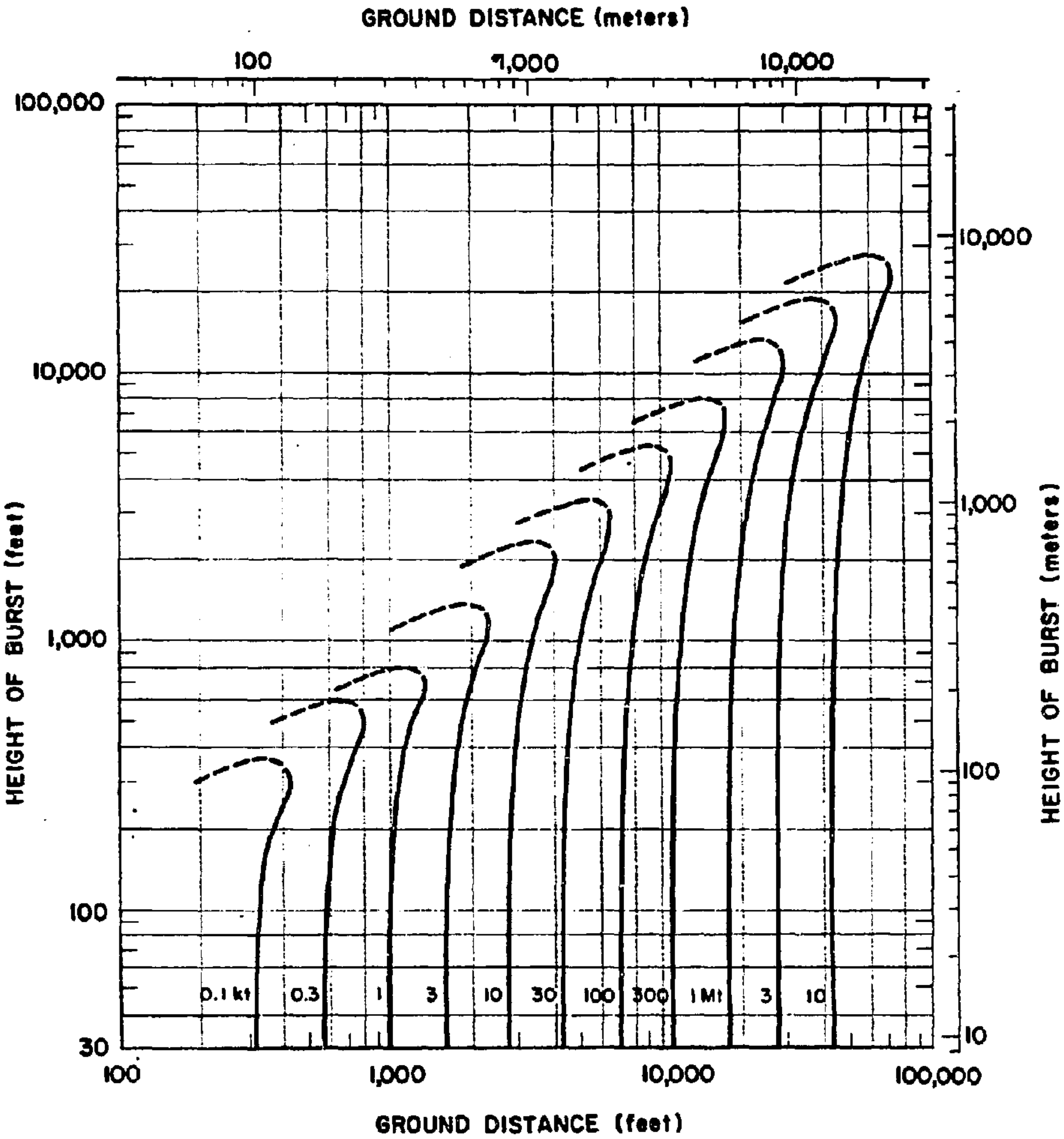

Figure 15-2. [redacted] Moderate Damage to a Type I Forest [redacted]

[redacted]

[redacted]

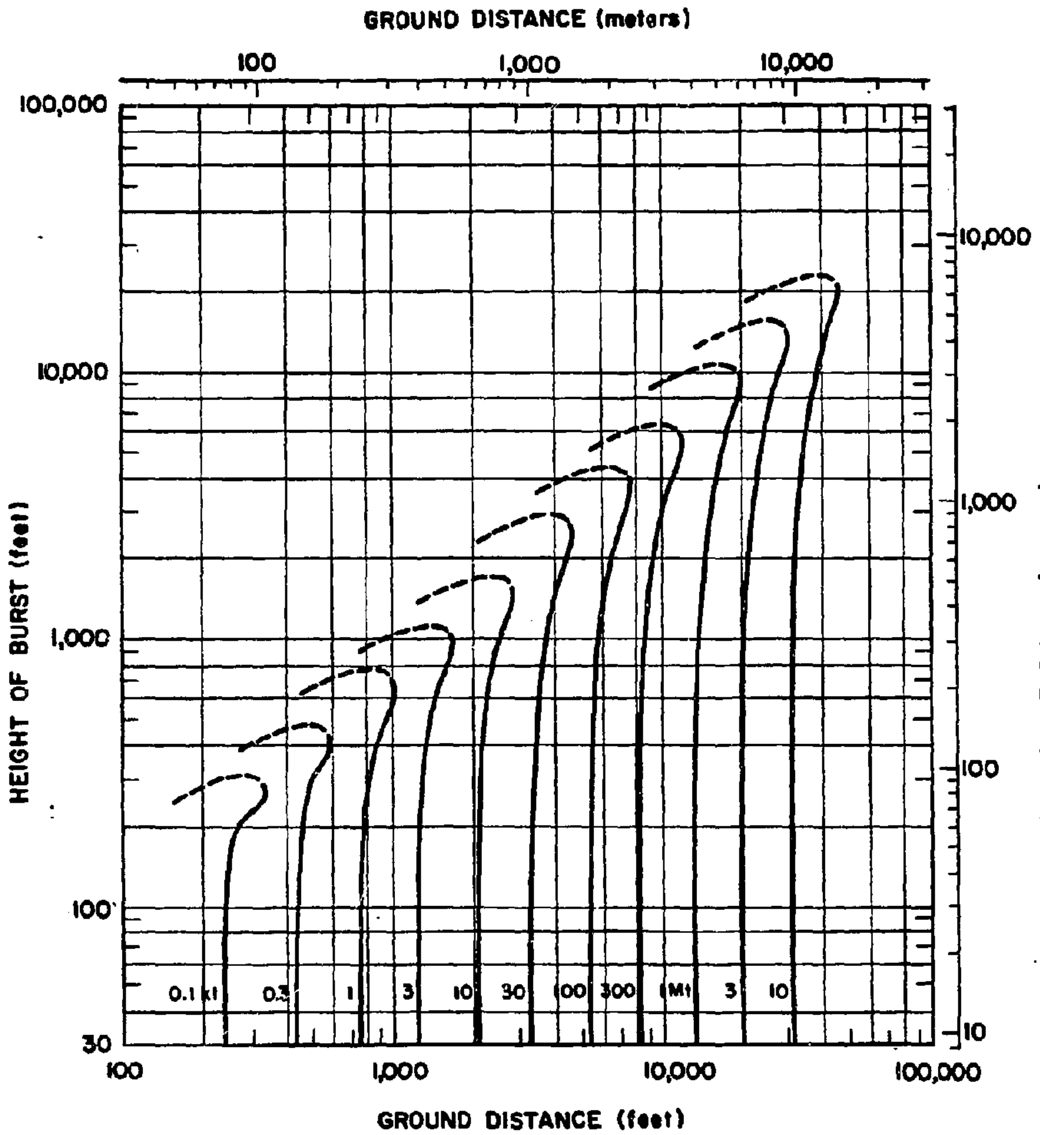

Figure 15-3. [redacted] Severe Damage to a Type I Forest [redacted]

[redacted]

[redacted]

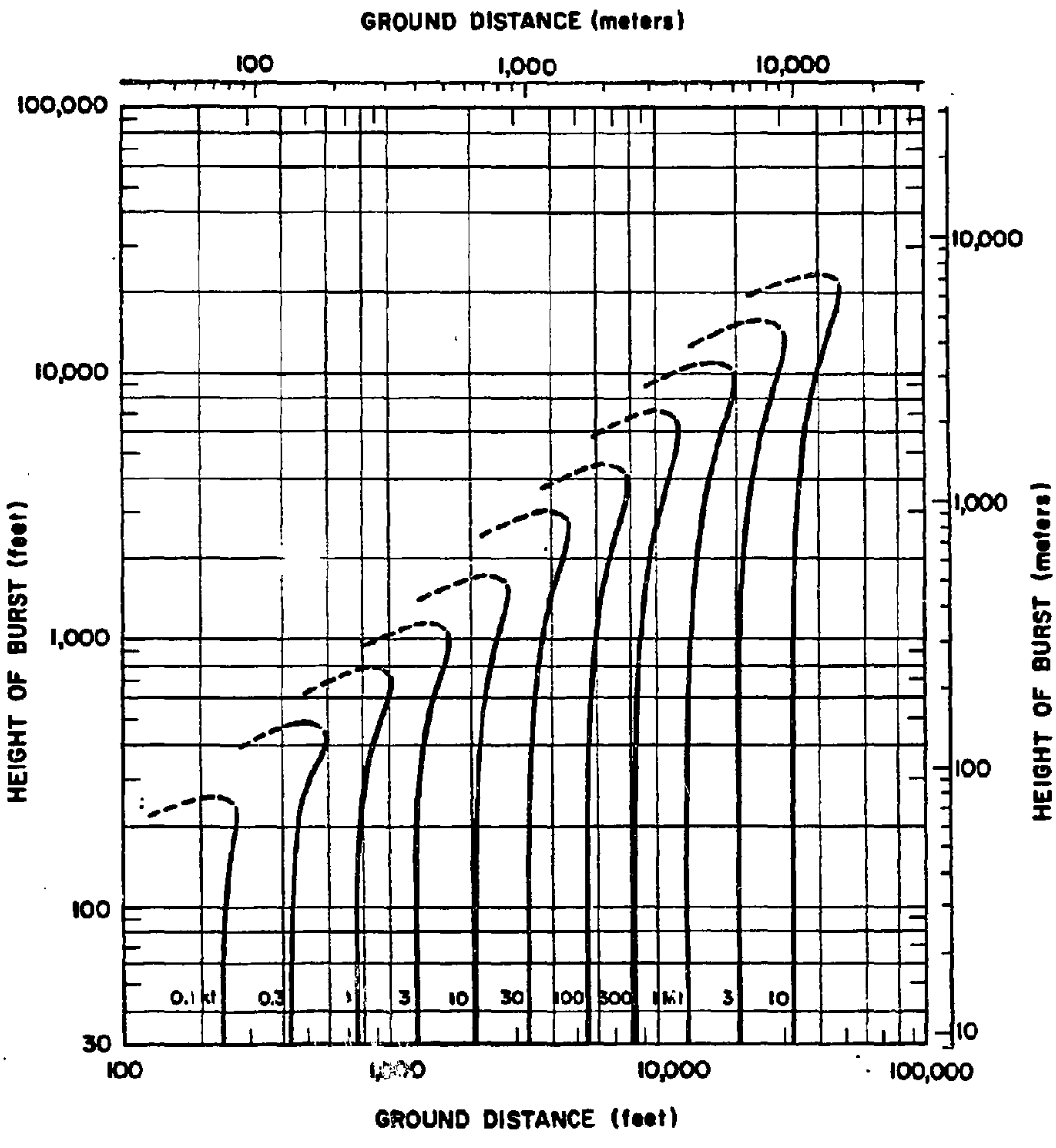

Figure 15-4. [redacted] Total Damage to a Type I Forest [redacted]

[redacted]

[redacted]

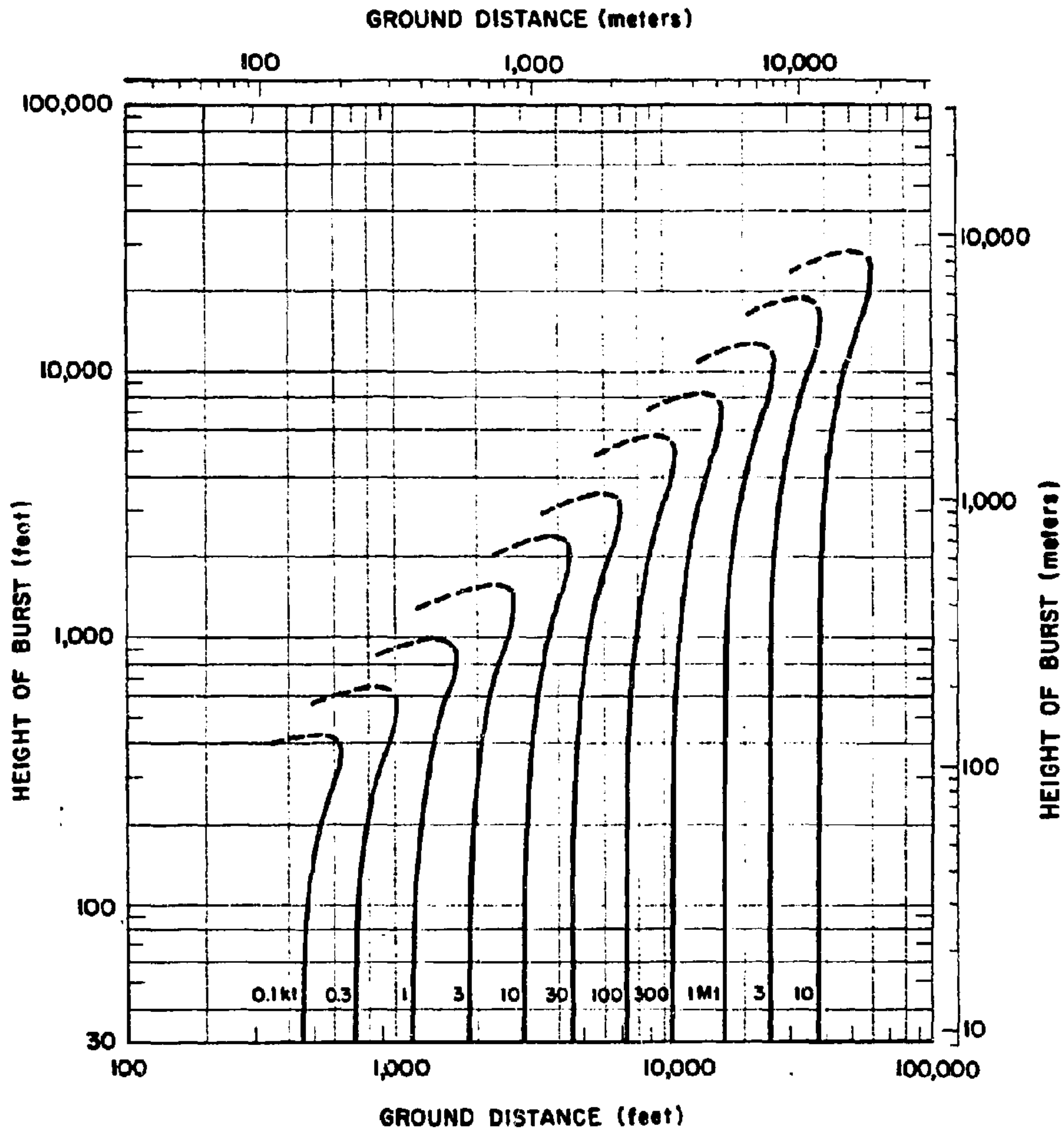

Figure 15-5. [redacted] Moderate Damage to a Type II Forest [redacted]

[redacted]

[redacted]

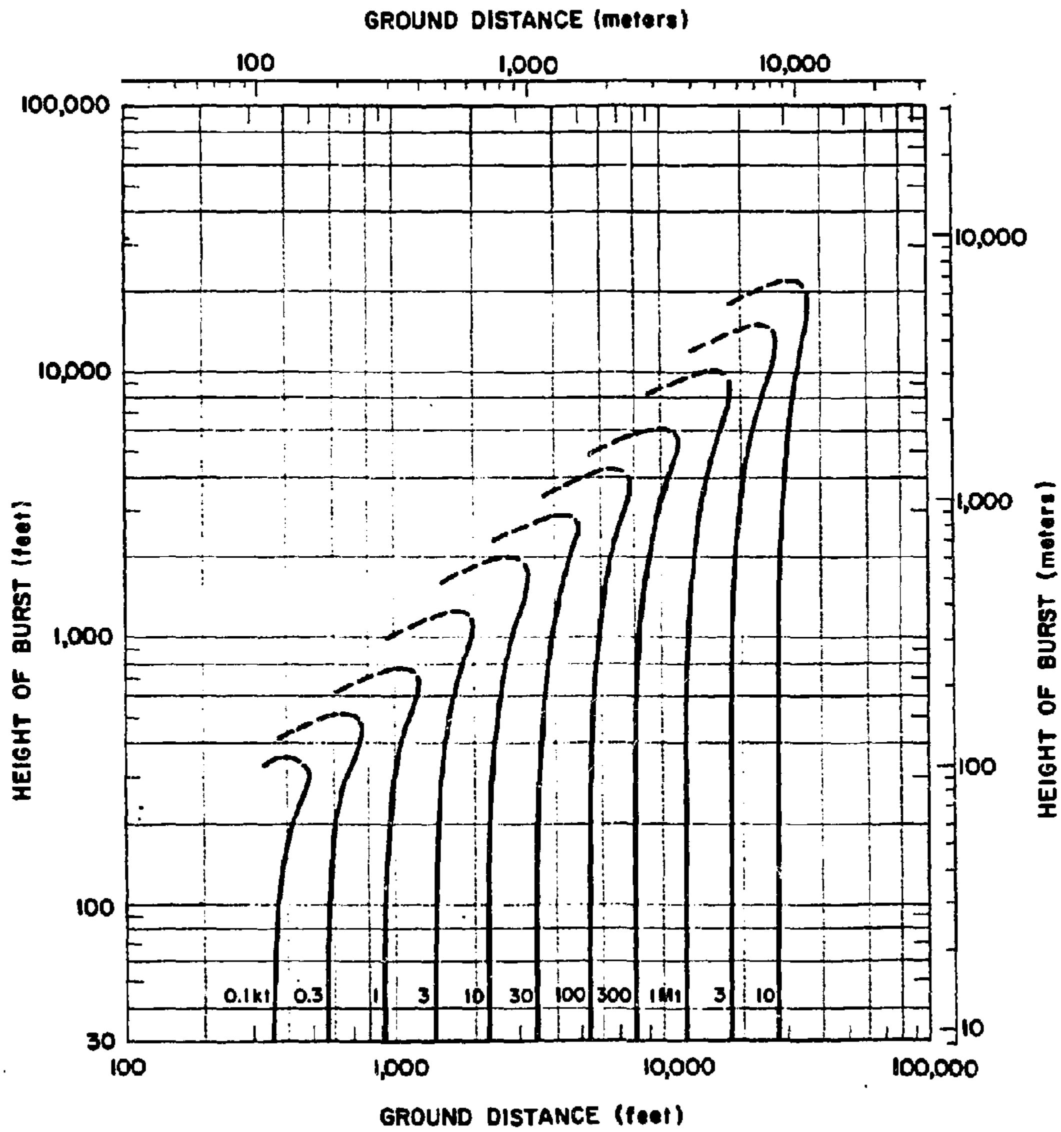

Figure 15-6. [redacted] Severe Damage to a Type II Forest [redacted]

[redacted]

[redacted]

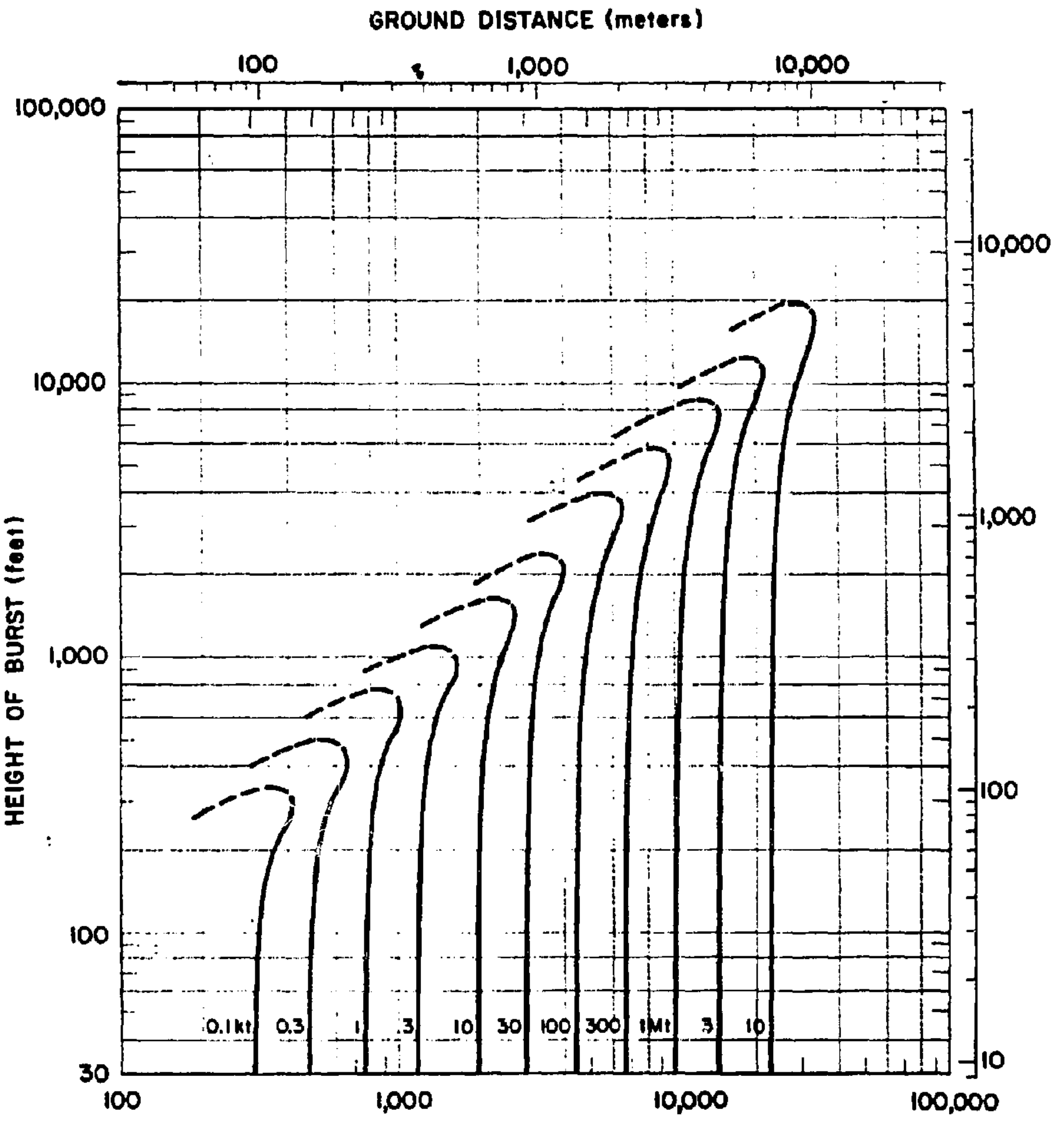

Figure 15-7. [redacted] Total Damage to a Type II Forest [redacted]

[redacted]

[redacted]

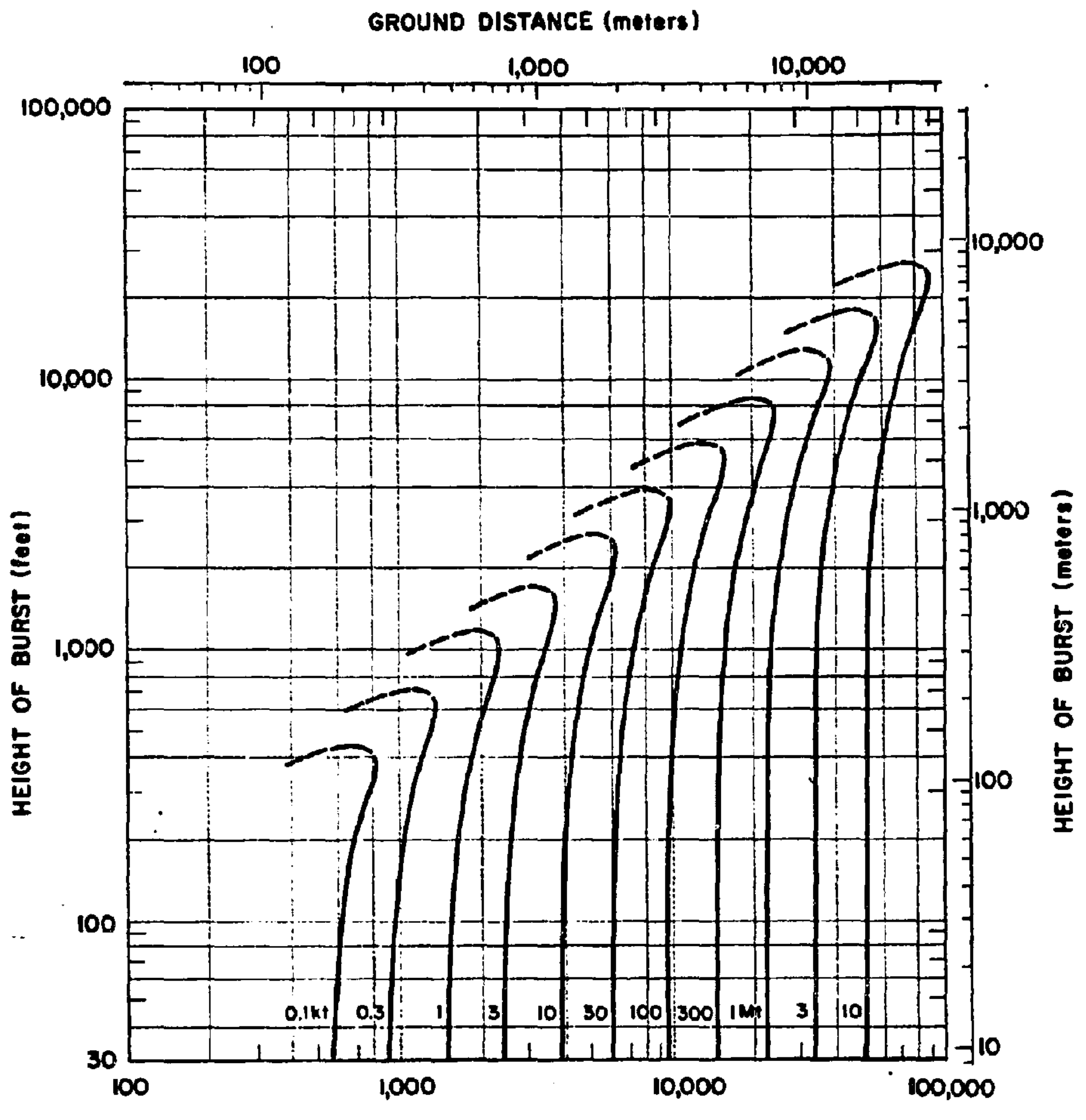

Figure 15-8. [redacted] Moderate Damage to a Type III Forest [redacted]

[redacted]

[redacted]

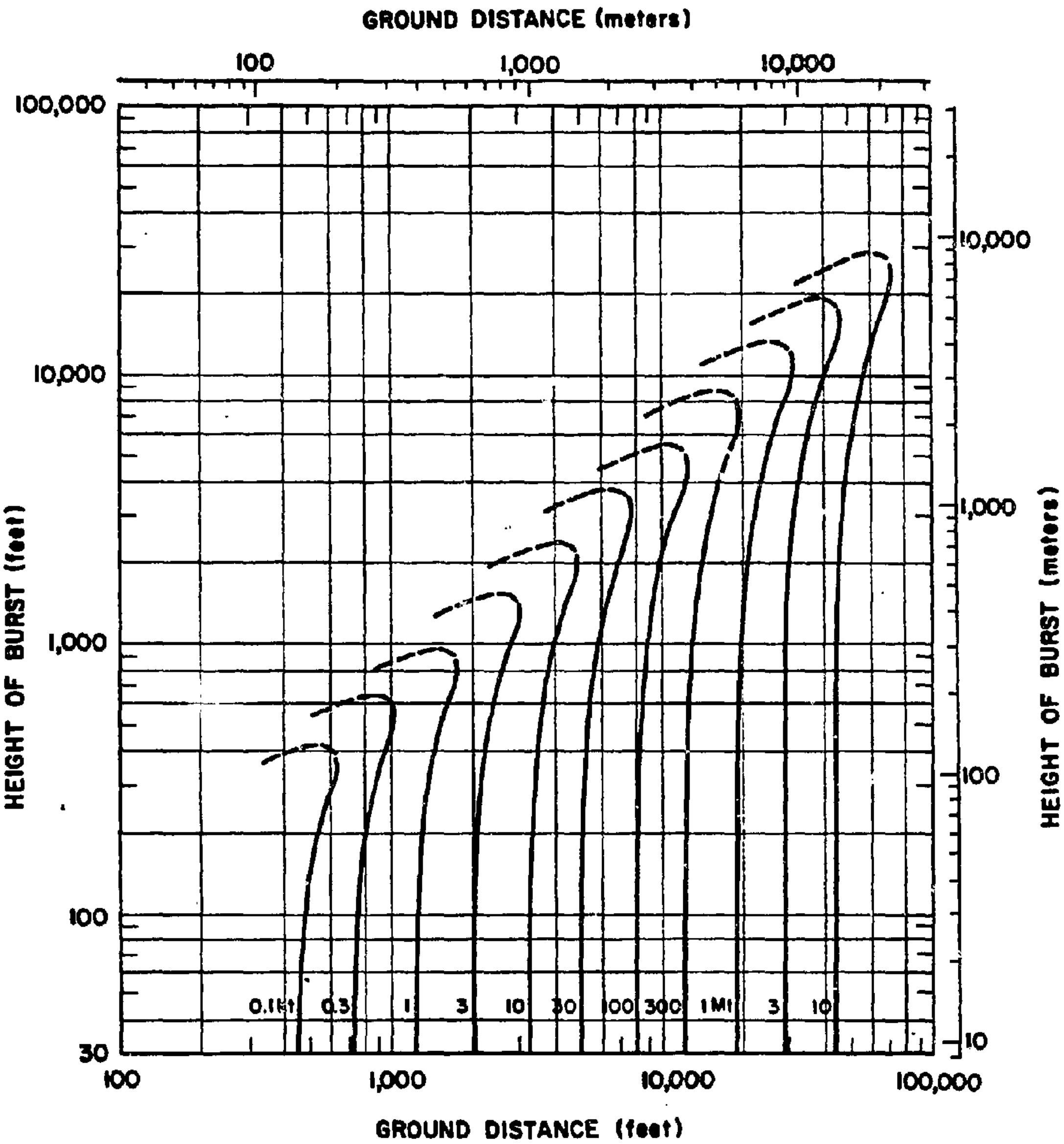

Figure 15-9. [redacted] Severe Damage to a Type III Forest [redacted]

[redacted]

[redacted]

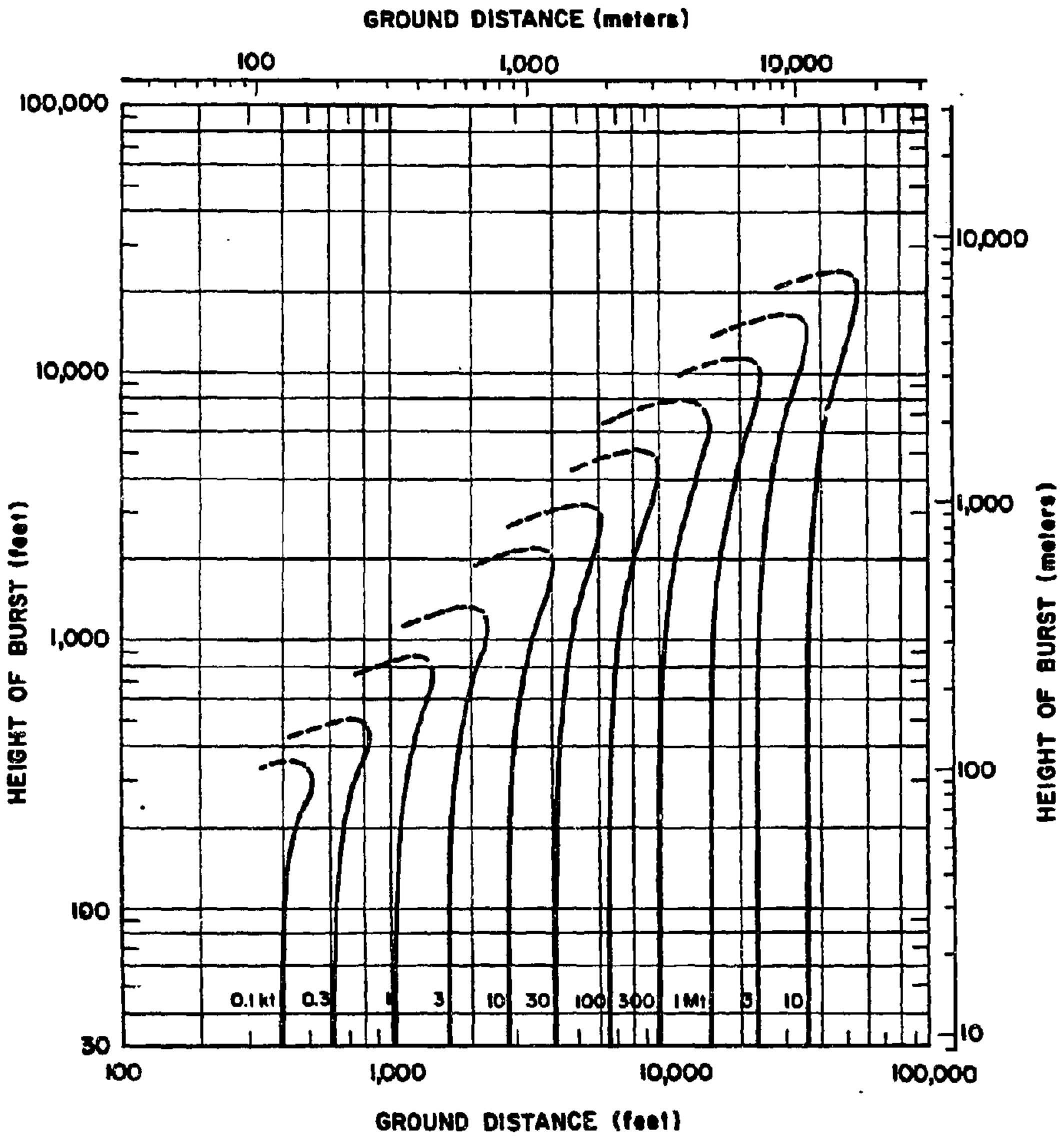

Figure 15-10. [redacted] Total Damage to a Type III Forest [redacted]

[redacted]

[redacted]

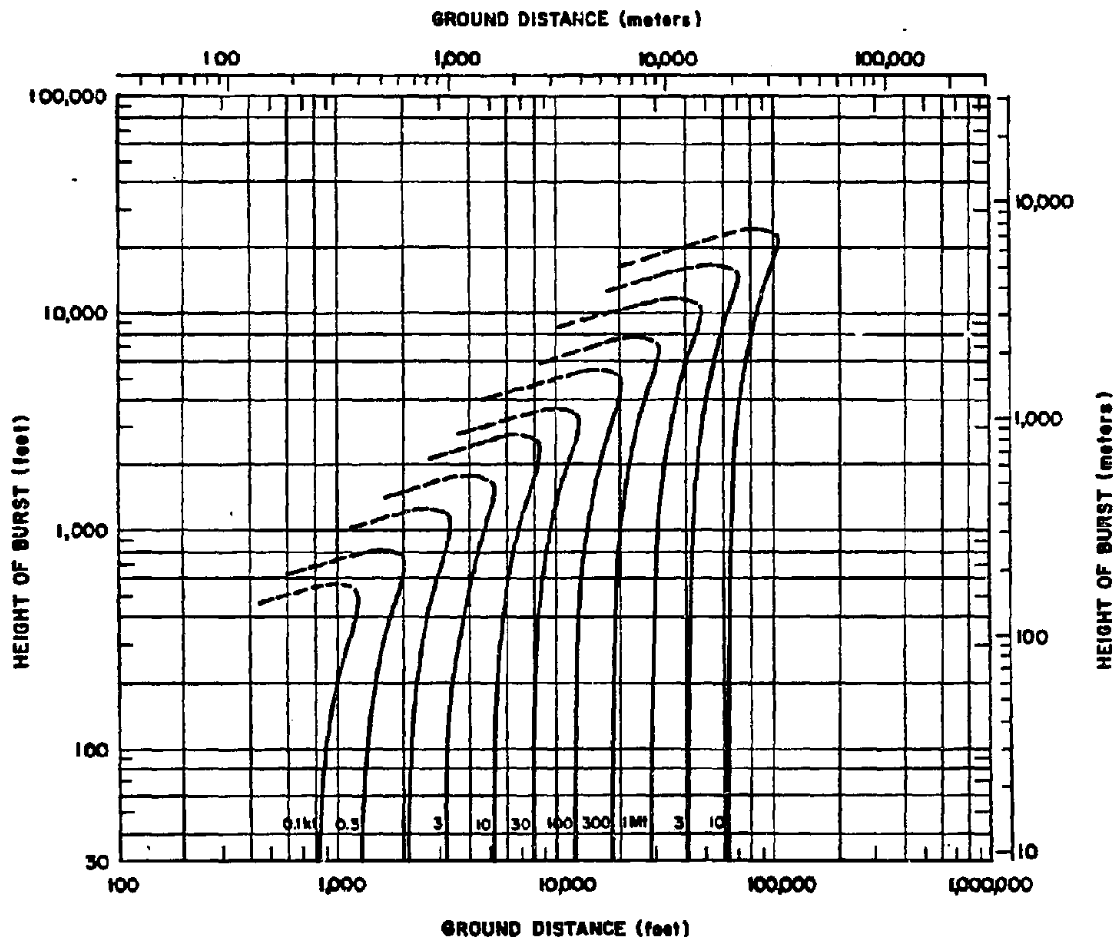

Figure 15-11. [redacted] Moderate Damage to a Type IVa-1(f) Forest [redacted]

[redacted]

[redacted]

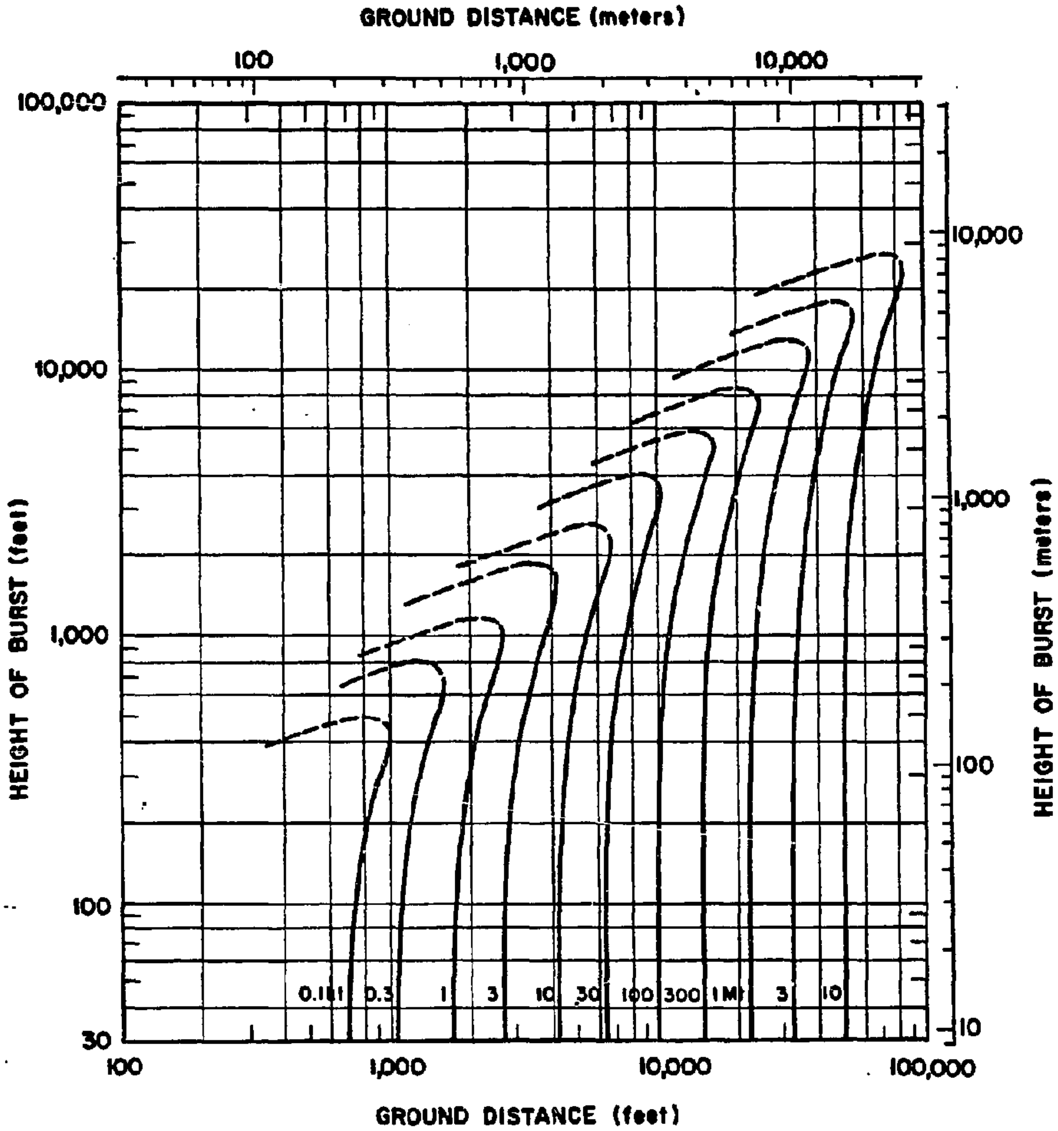

Figure 15-12. [redacted] Severe Damage to a Type IVa-1(f) Forest [redacted]

[redacted]

[redacted]

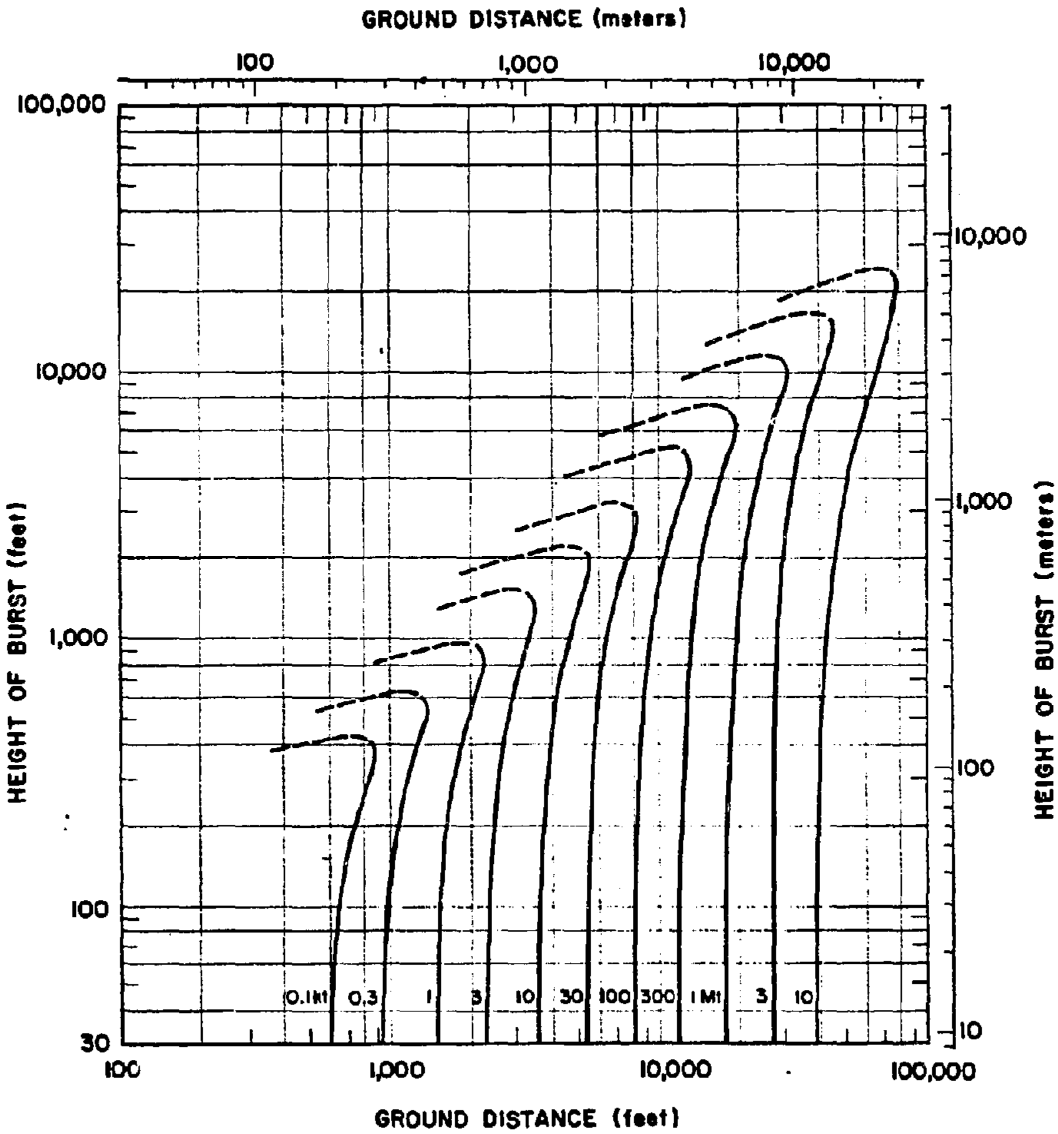

Figure 15-13. [redacted] Total Damage to a Type IVa-1(f) Forest [redacted]

[redacted]

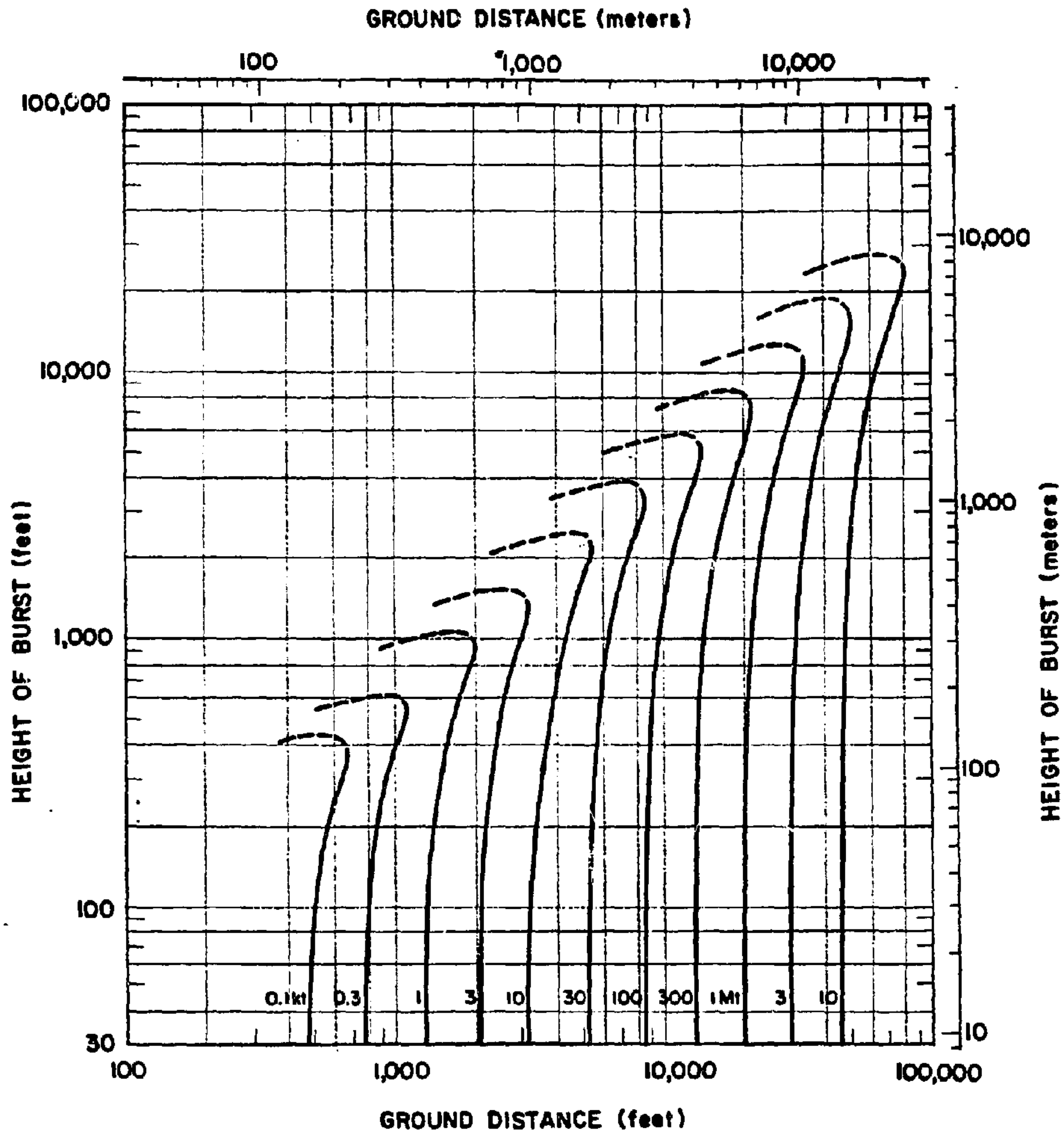

Figure 15-14. [redacted] Moderate Damage to a Type IVa-1(d) Forest [redacted]

[redacted]

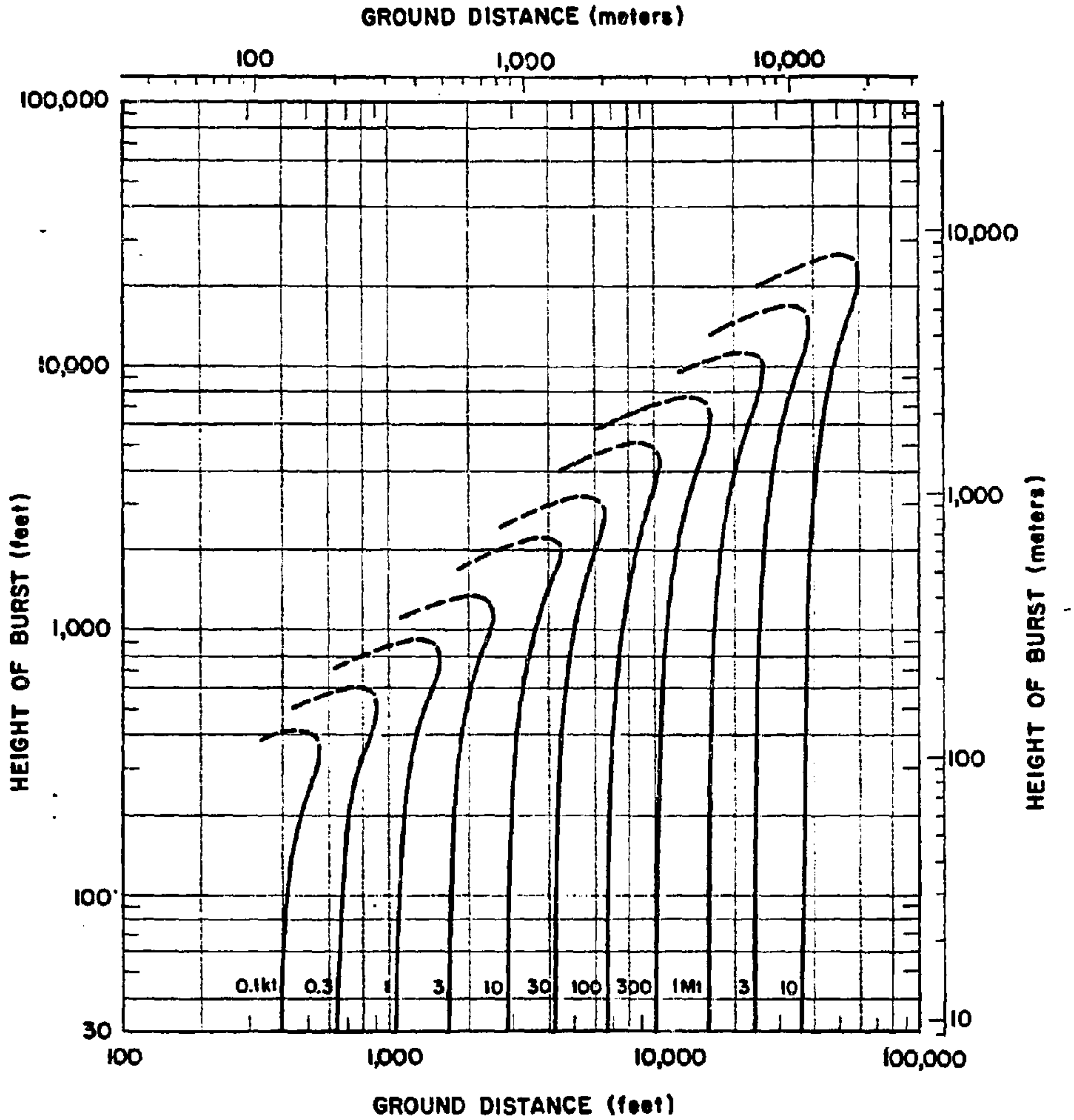

Figure 15-15. [redacted] Severe Damage to a Type IVa-1(d) Forest [redacted]

[redacted]

[redacted]

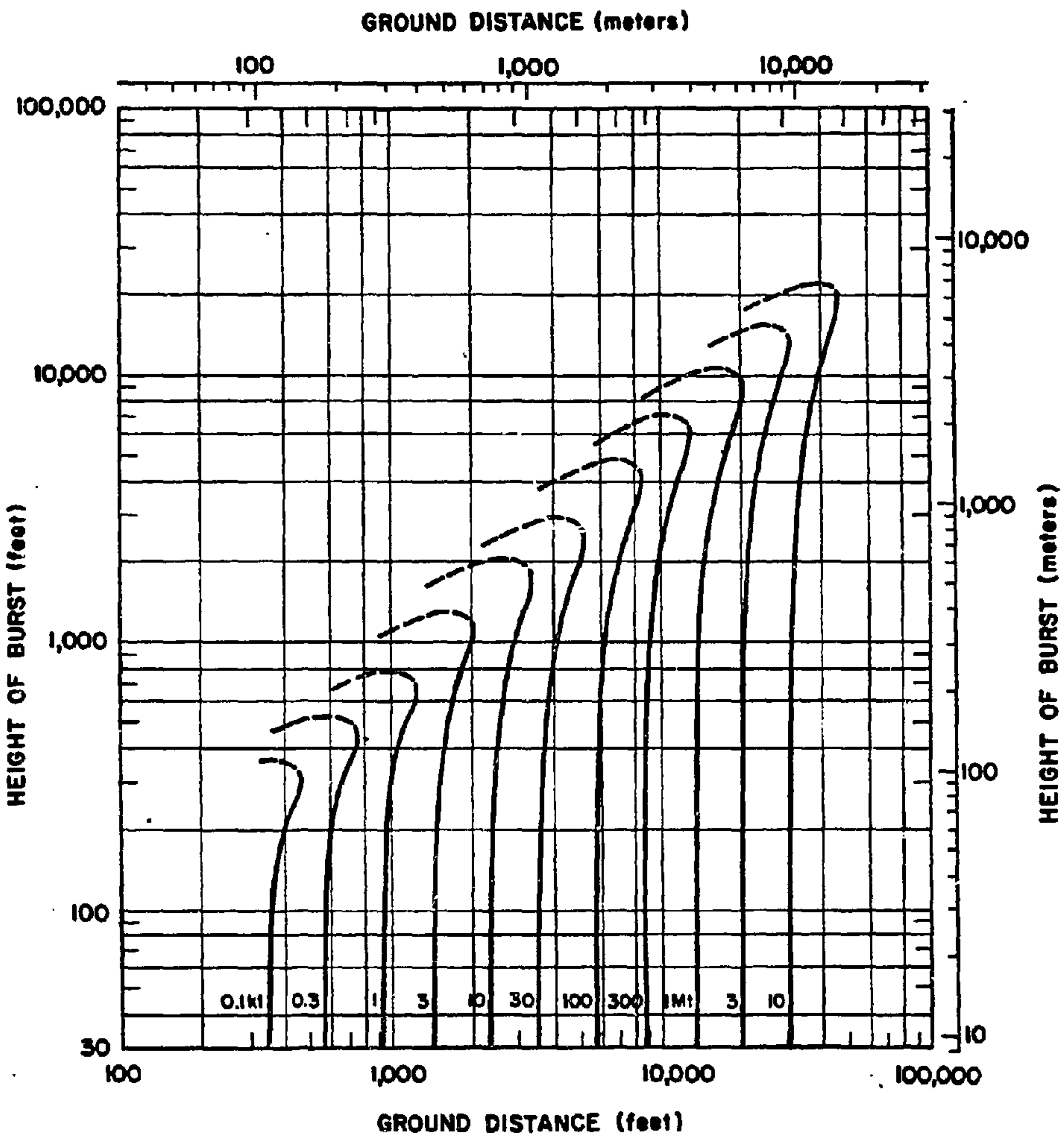

Figure 15-16. [redacted] Total Damage to a Type IVa-1(d) Forest [redacted]

[redacted]

[redacted]

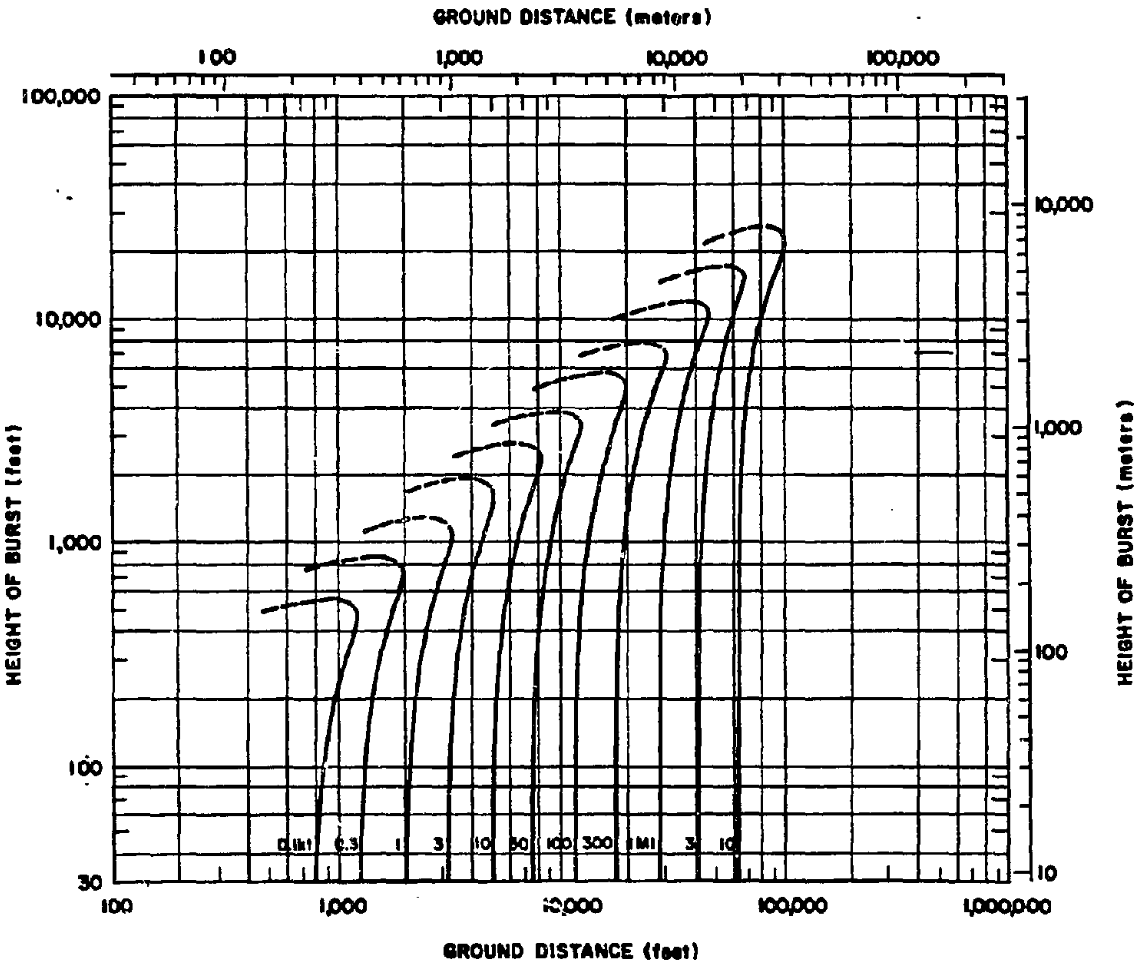

Figure 15-17. [redacted] Moderate Damage to a Type IVa-2(f) Forest [redacted]

[redacted]

[redacted]

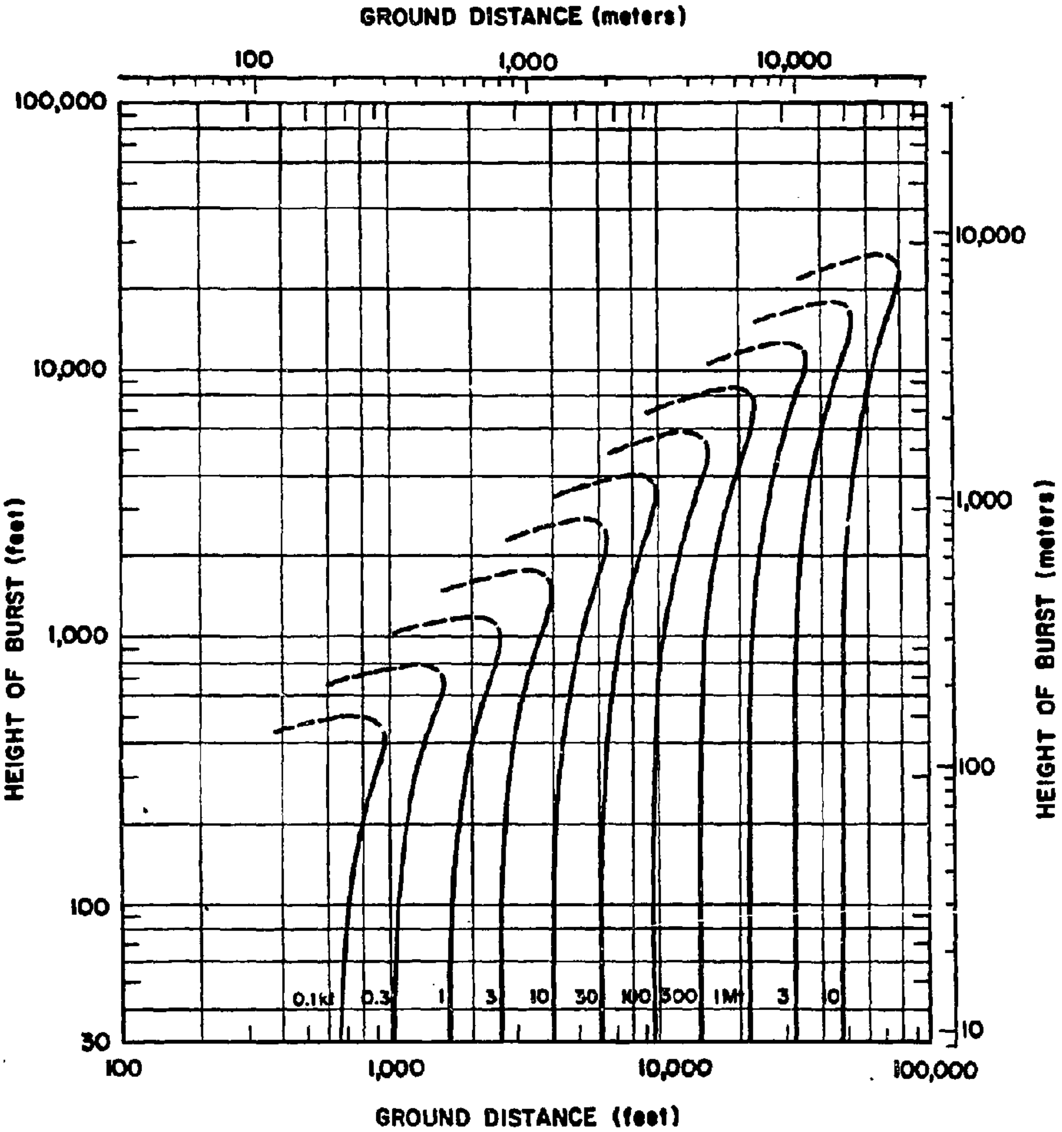

Figure 15-18. [redacted] Severe Damage to a Type IVa-2(f) Forest [redacted]

[redacted]

[redacted]

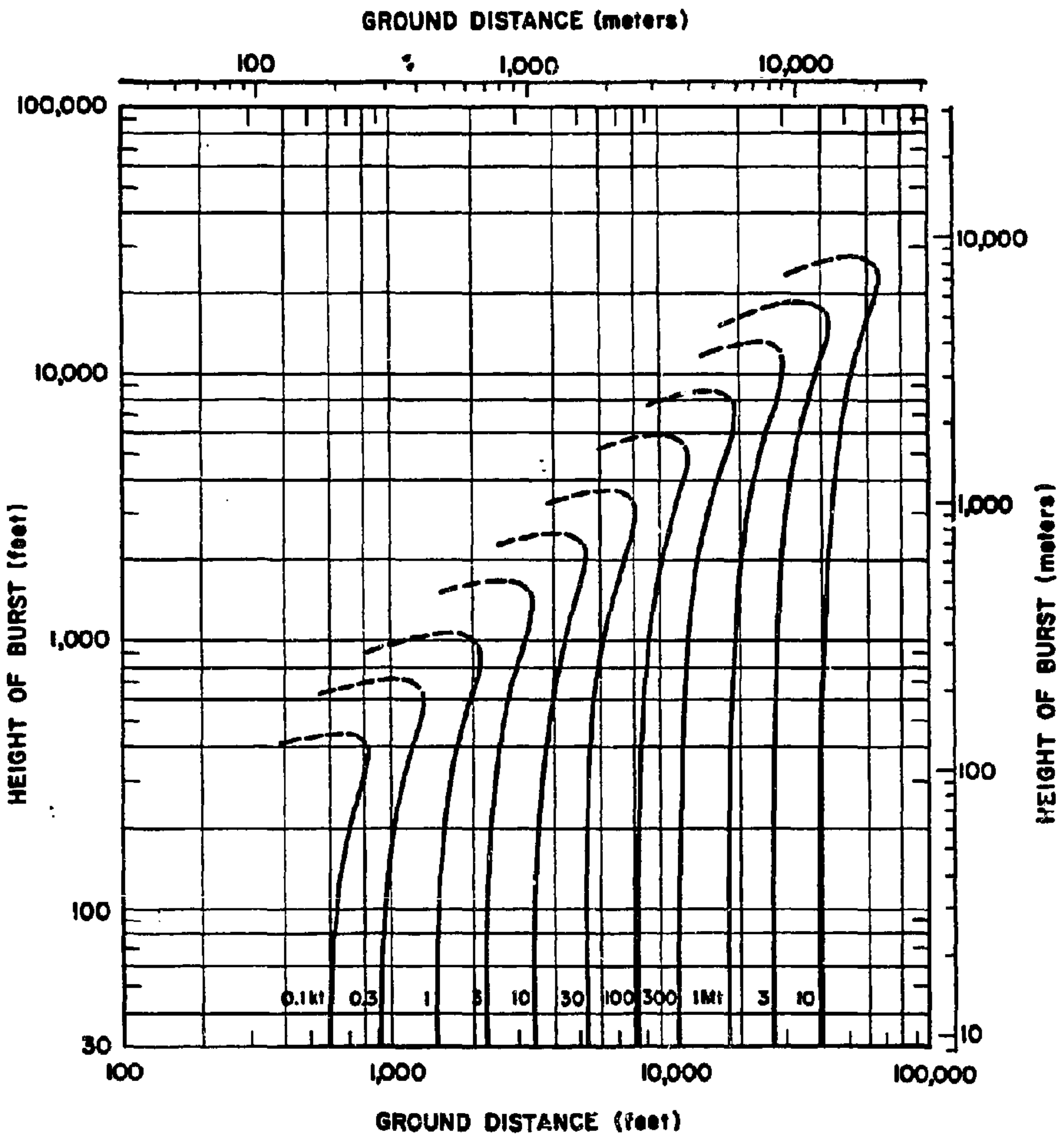

Figure 15-19. [redacted] Total Damage to a Type IVa-2(f) Forest [redacted]

[redacted]

[redacted]

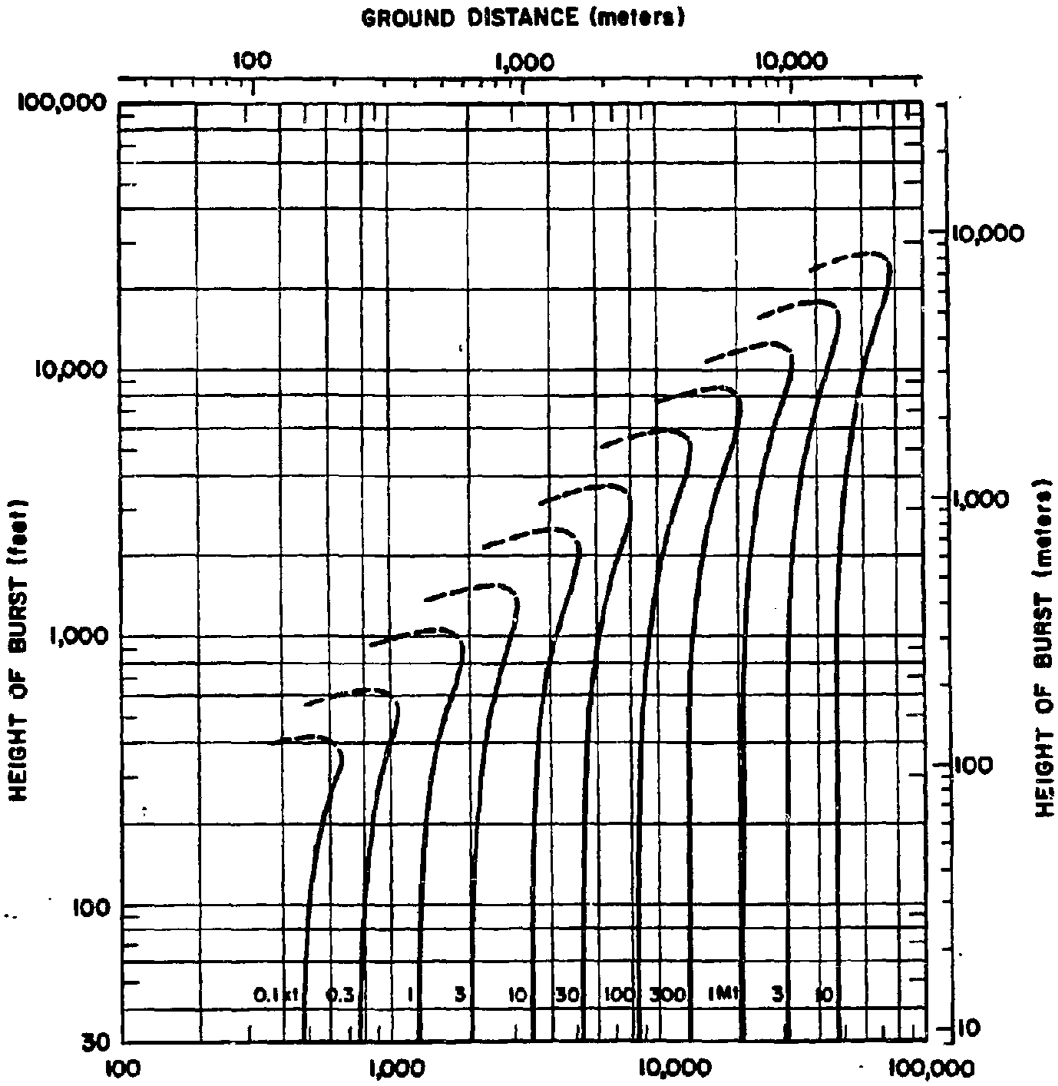

Figure 15-20 [redacted] Moderate Damage to a Type IVa-2(d) Forest [redacted]

[redacted]

[redacted]

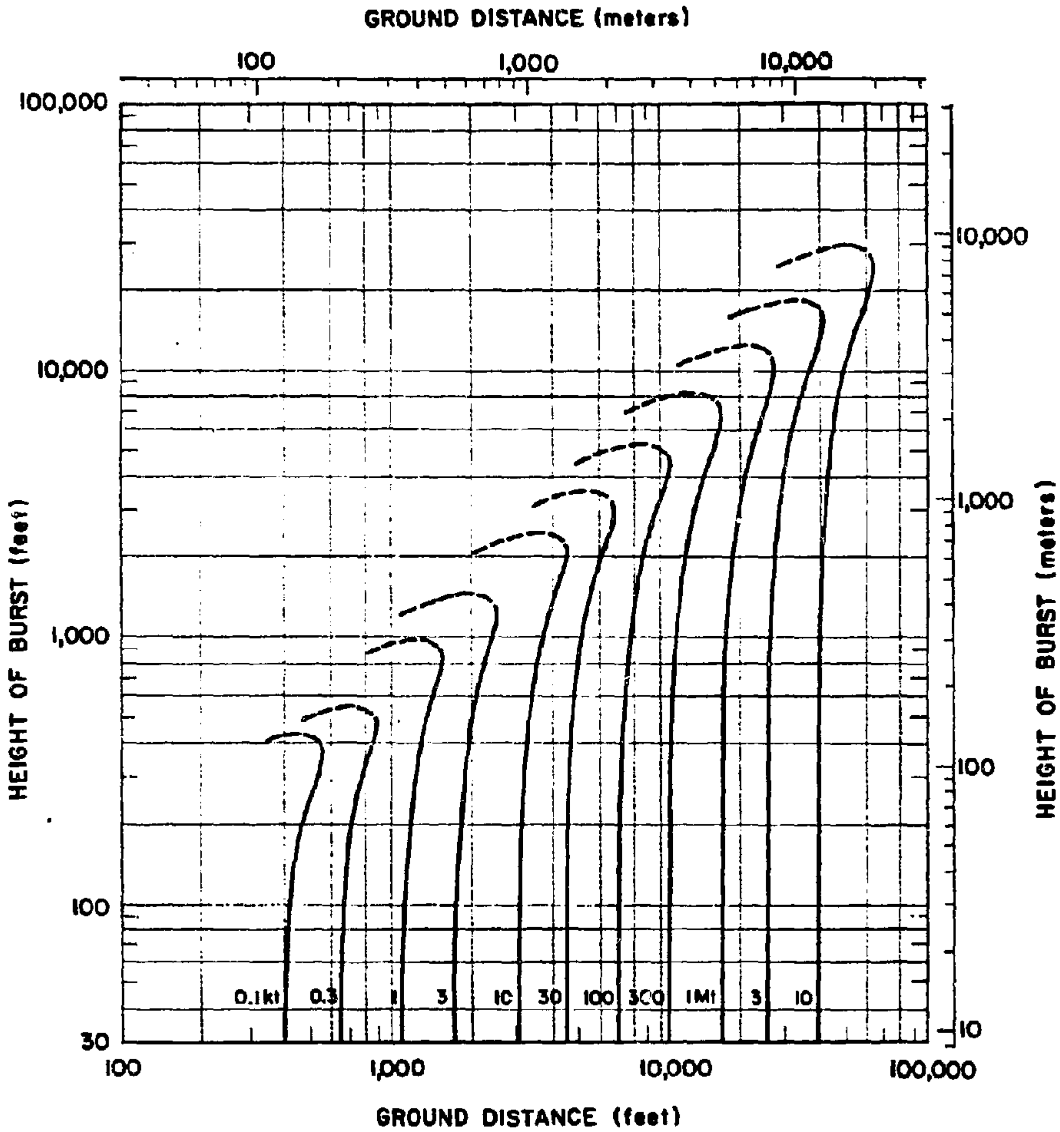

Figure 15-21. [redacted] Severe Damage to a Type IVa-2(d) Forest [redacted]

[redacted]

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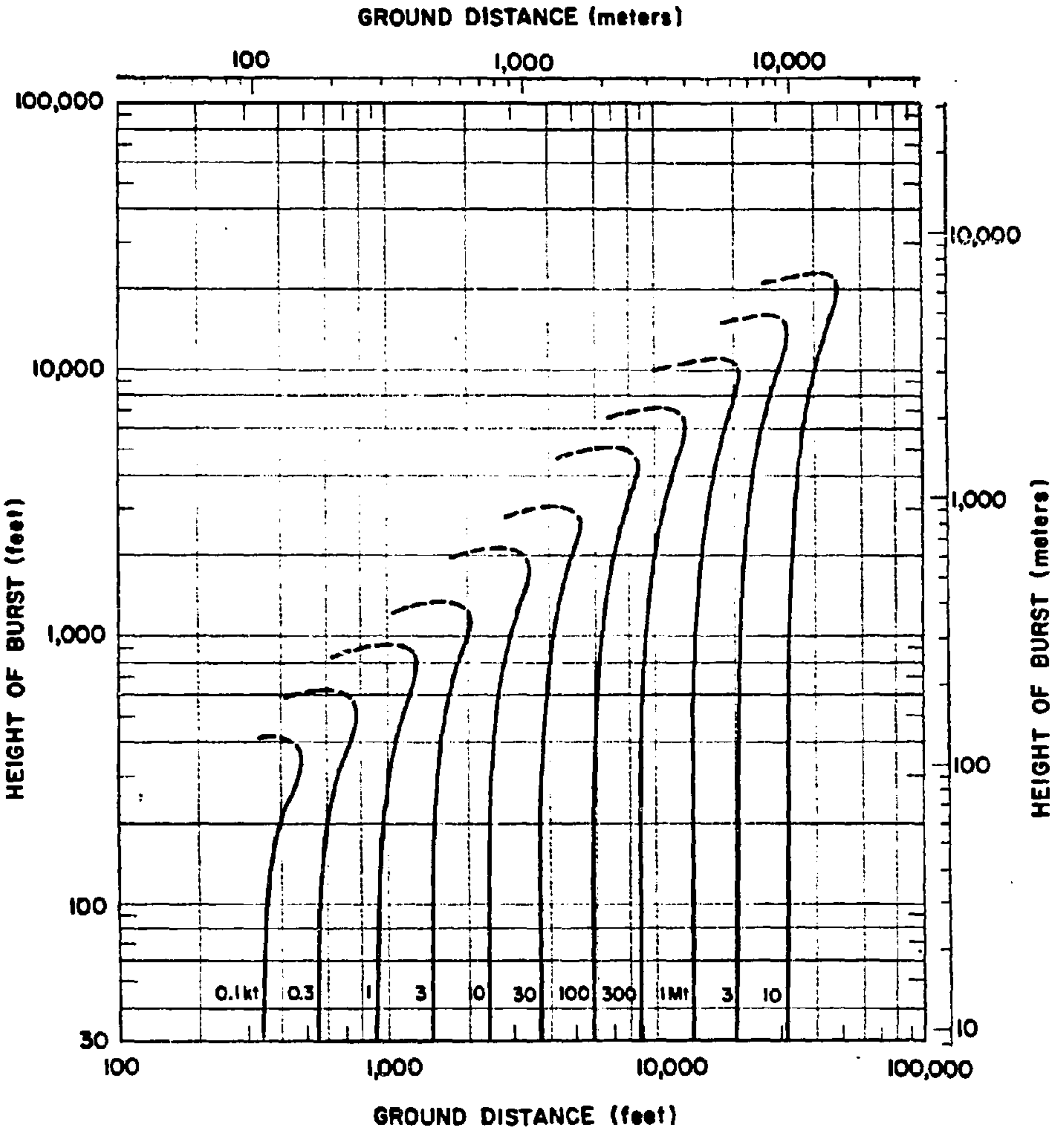

Figure 15-22. [redacted] Total Damage to a Type IVa-2(d) Forest [redacted]

[redacted]

[redacted]

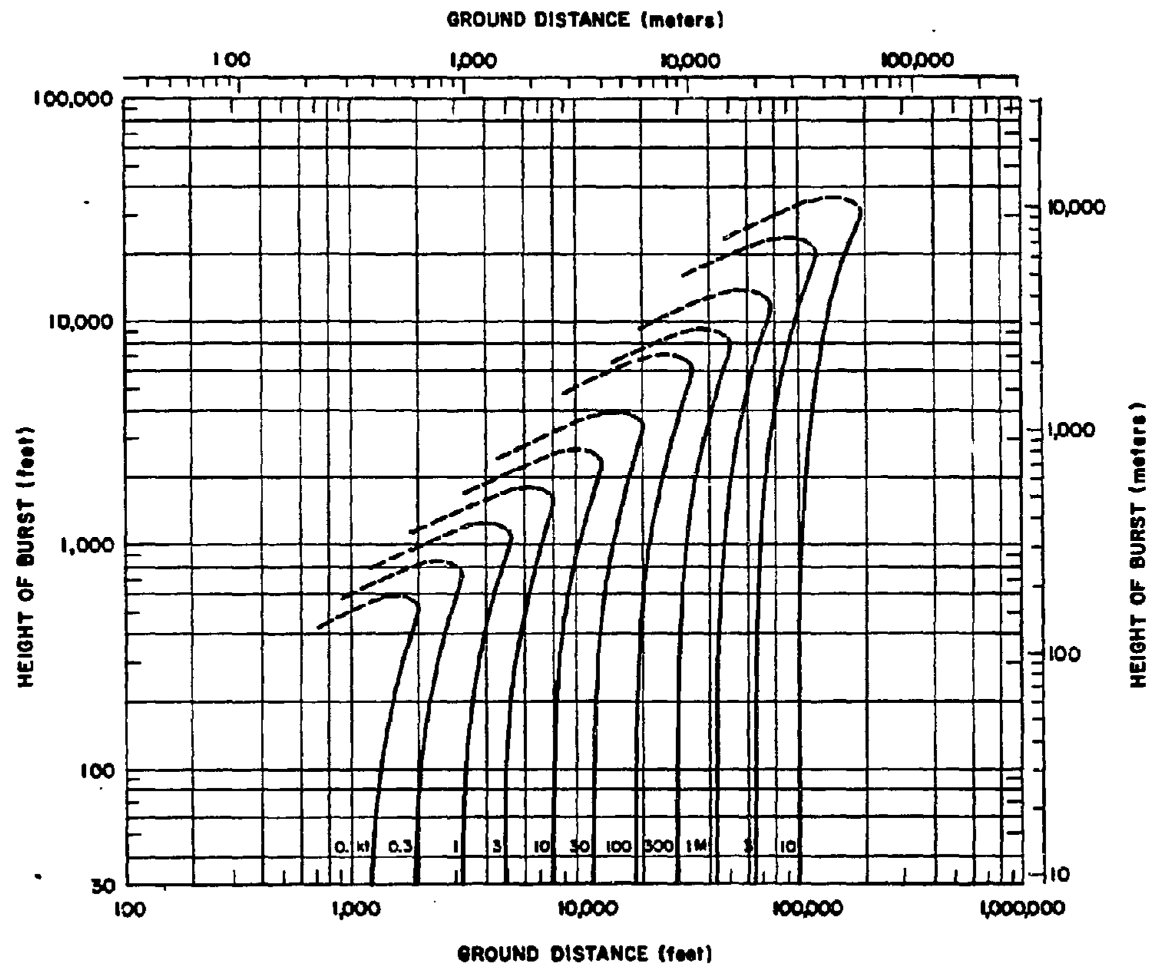

Figure 15-23. [redacted] Moderate Damage to a Type IVb(f) Forest [redacted]

[redacted]

[redacted]

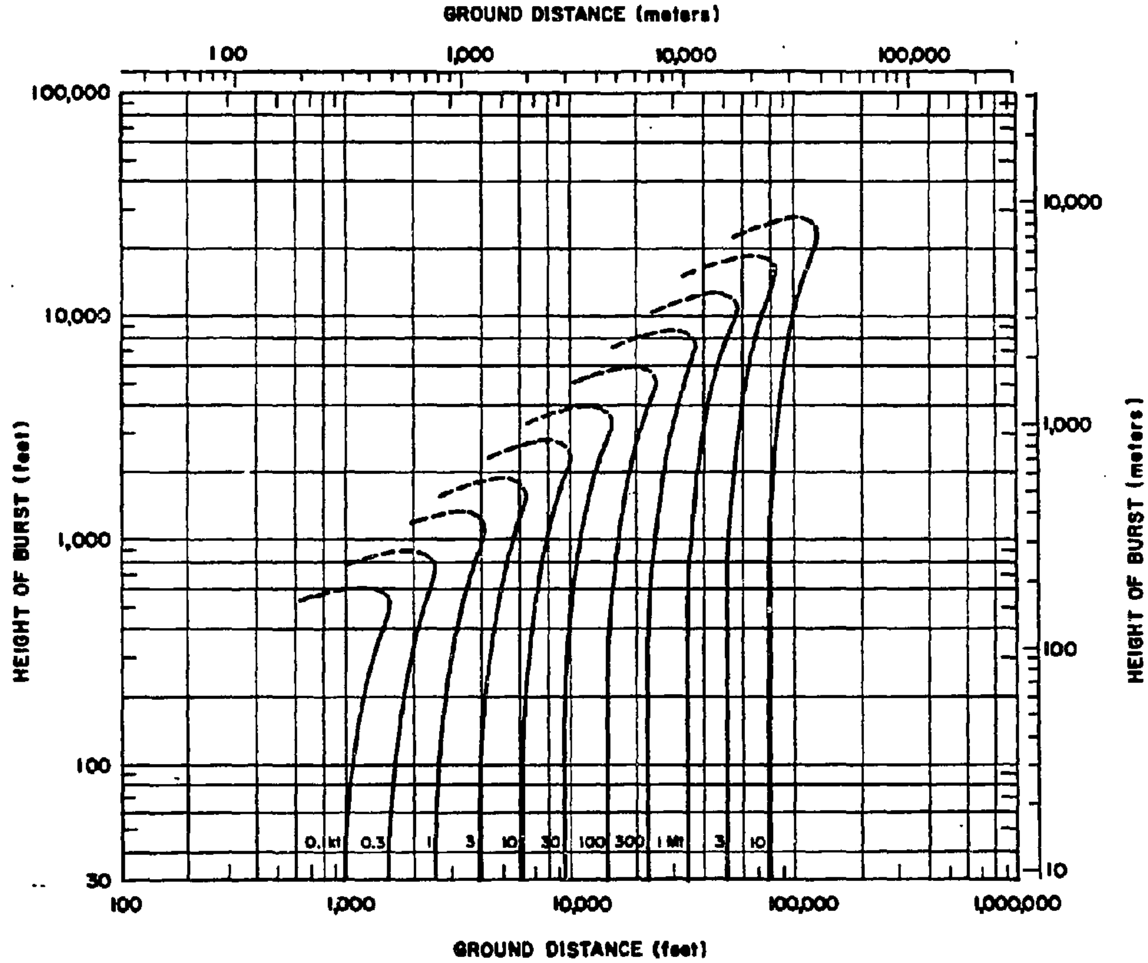

Figure 15-24. [redacted] Severe Damage to a Type IVb(f) Forest [redacted]

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[redacted]

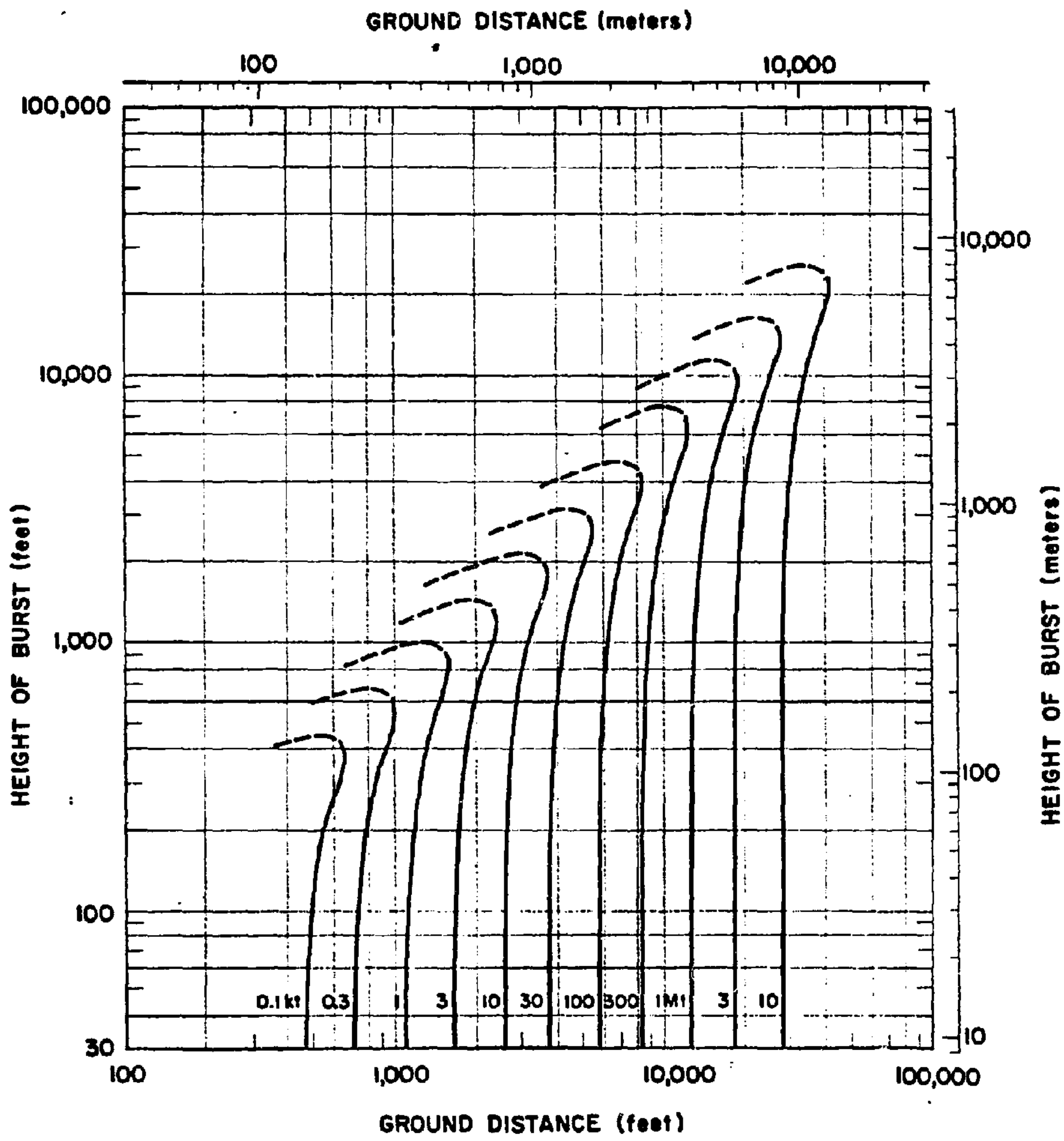

Figure 15-25. [redacted] Total Damage to a Type IVb(f) Forest [redacted]

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[redacted]

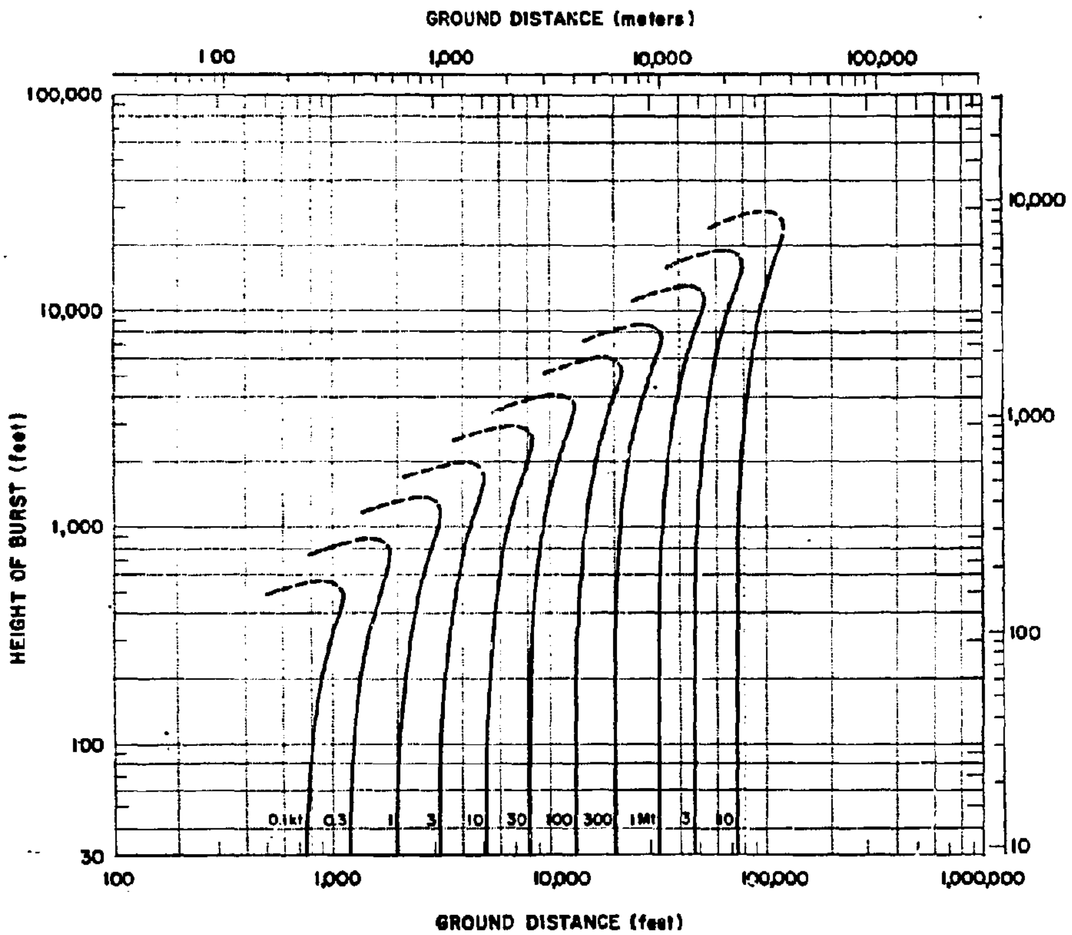

Figure 15-26. [redacted] Moderate Damage to a Type IVb(d) Forest [redacted]

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[redacted]

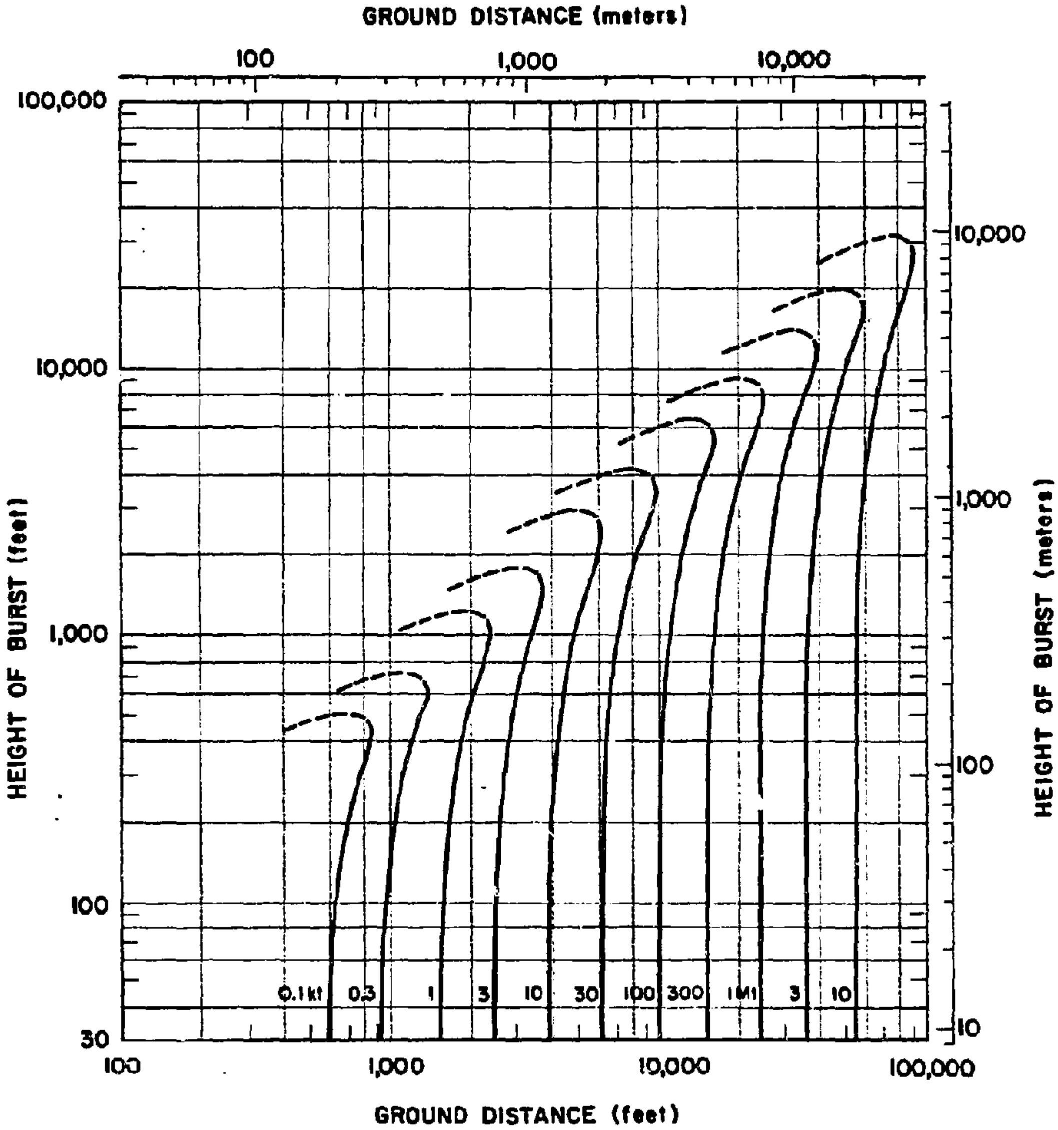

Figure 15-27. [redacted] Severe Damage to a Type IVb(d) Forest [redacted]

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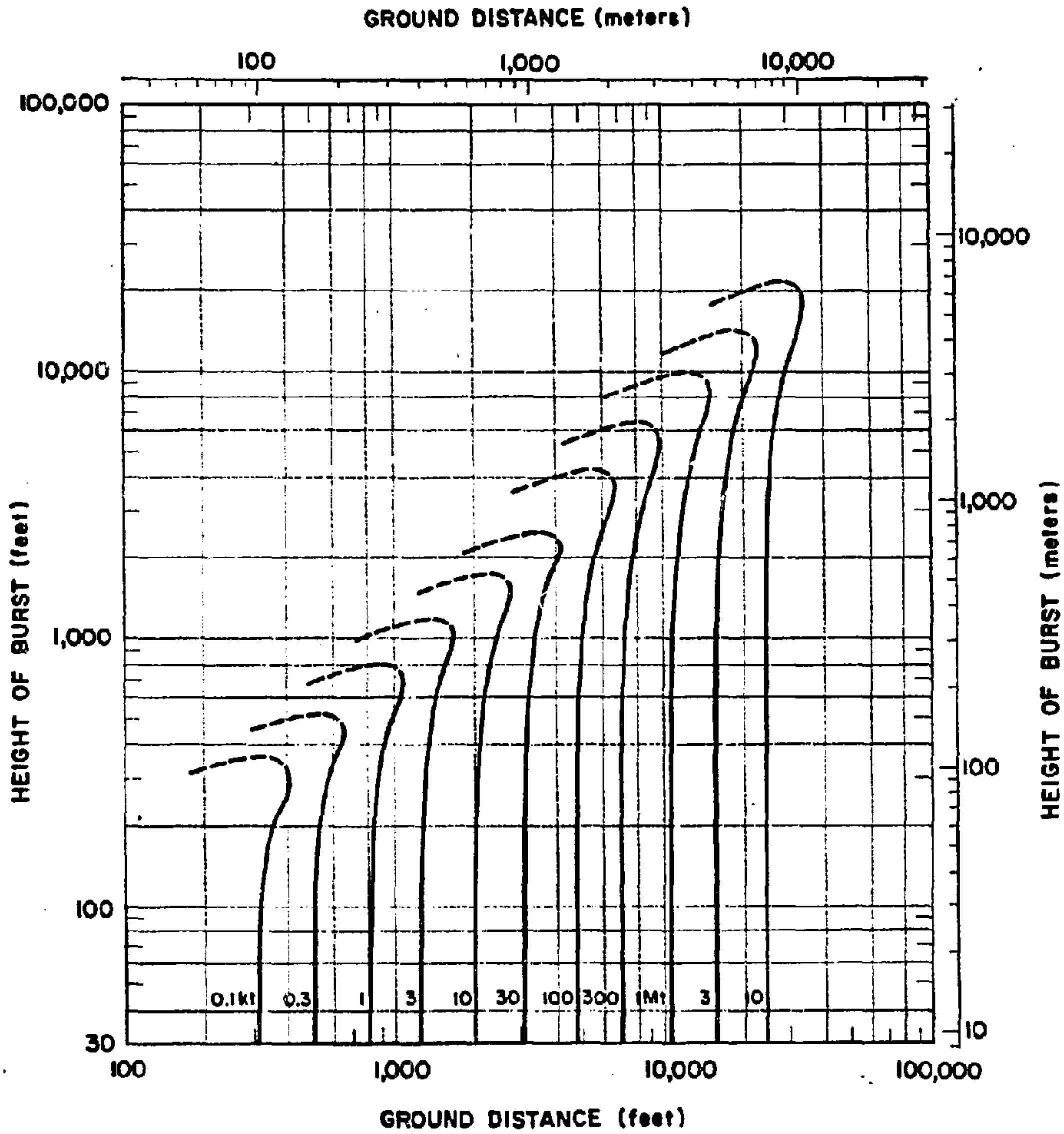

Figure 15-28. [redacted] Total Damage to a Type IVb(d) Forest [redacted]

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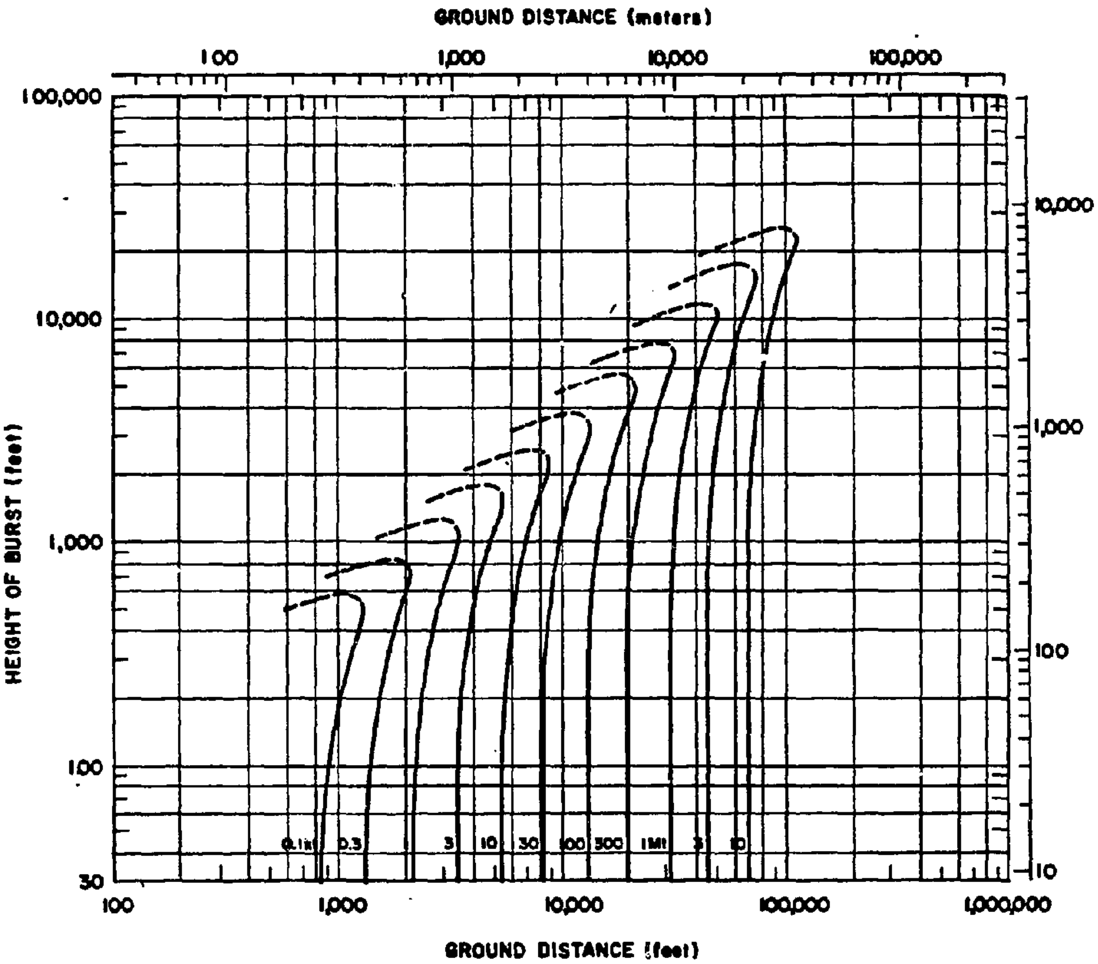

Figure 15-29. [redacted] Moderate Damage to a Type IVc(f) Forest [redacted]

[redacted]

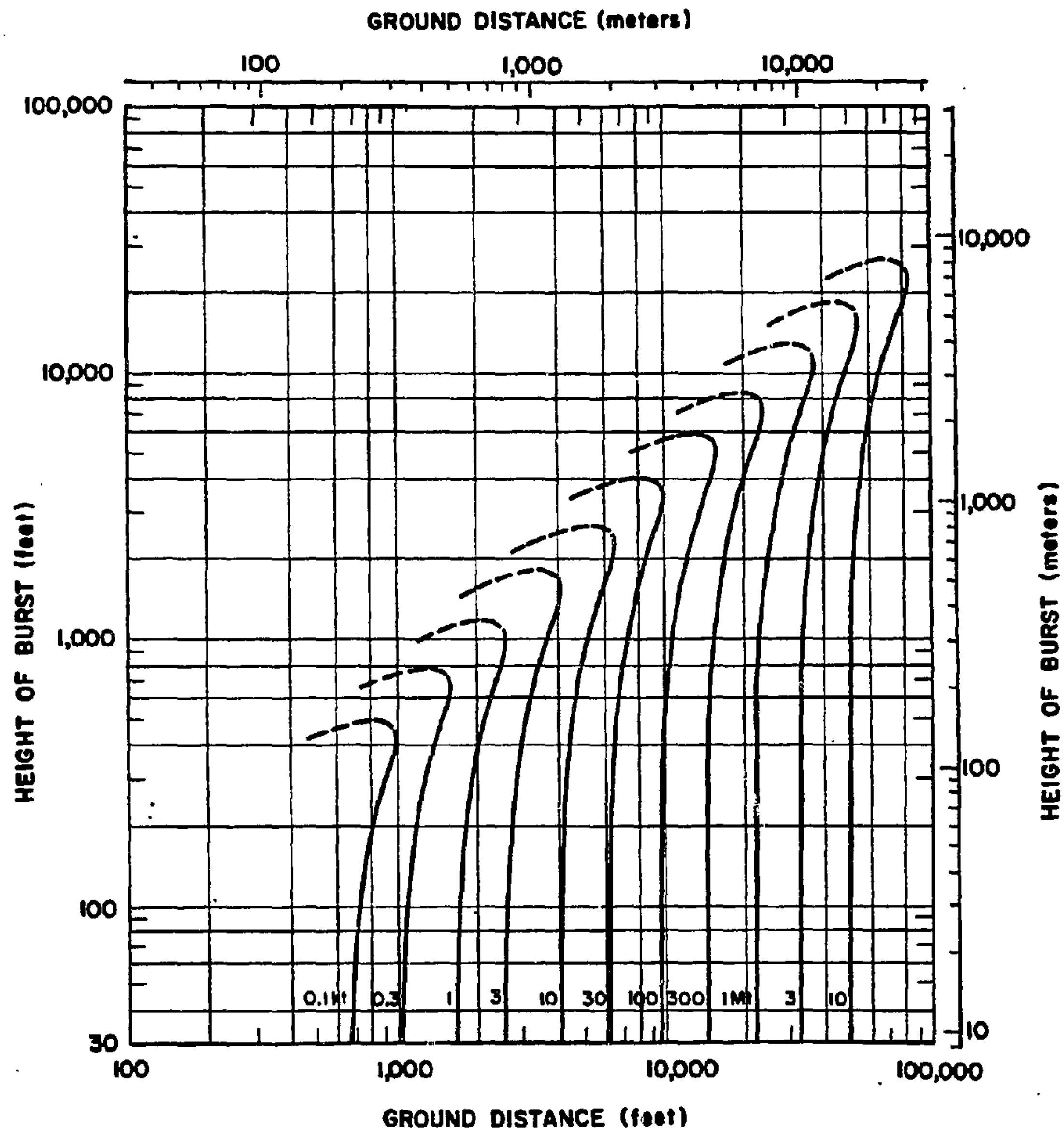

Figure 15-30. [redacted] Total Damage to a Type IVc(f) Forest [redacted]

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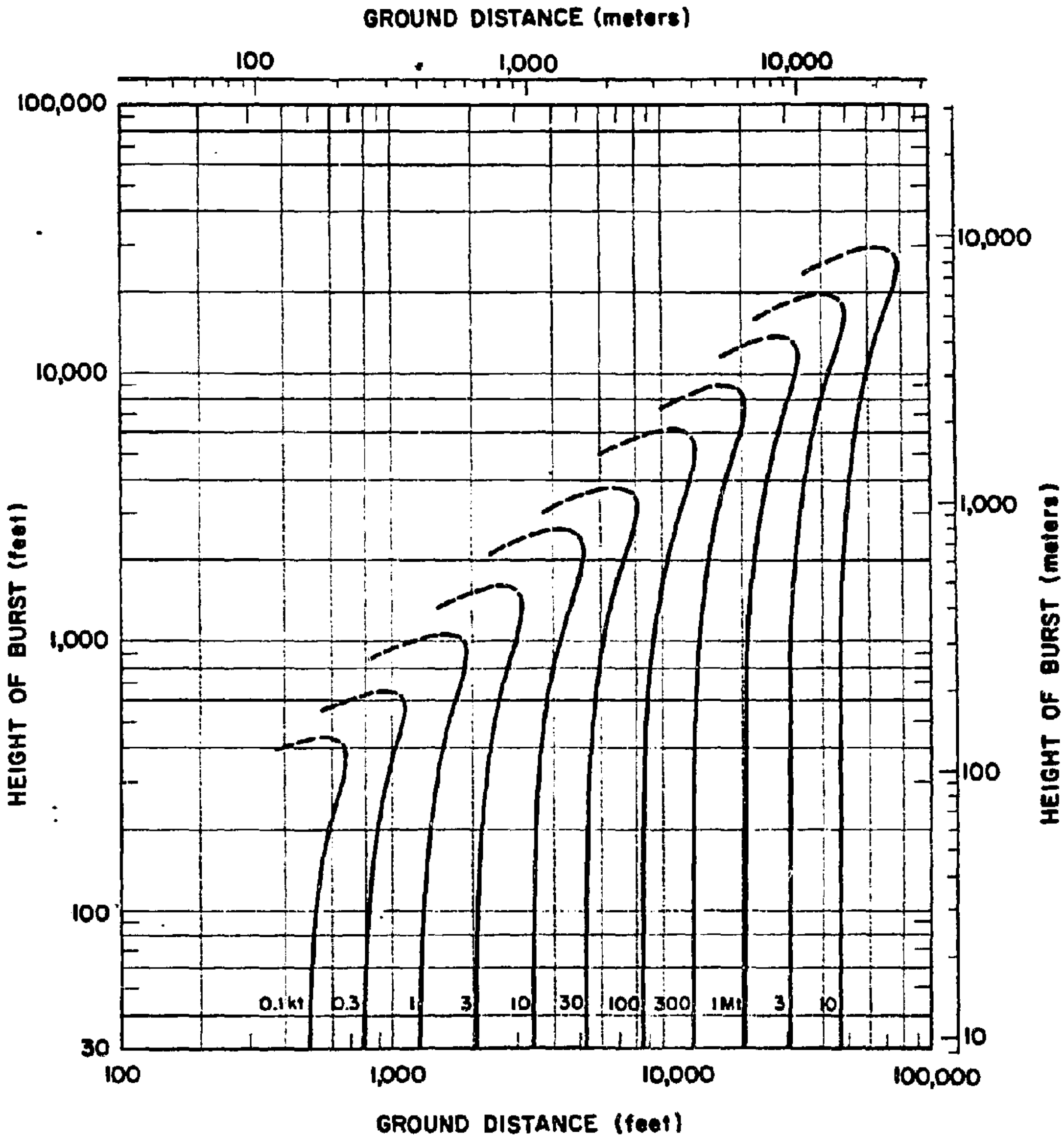

Figure 15-31. [redacted] Moderate Damage to a Type IVc(d) Forest [redacted]

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[redacted]

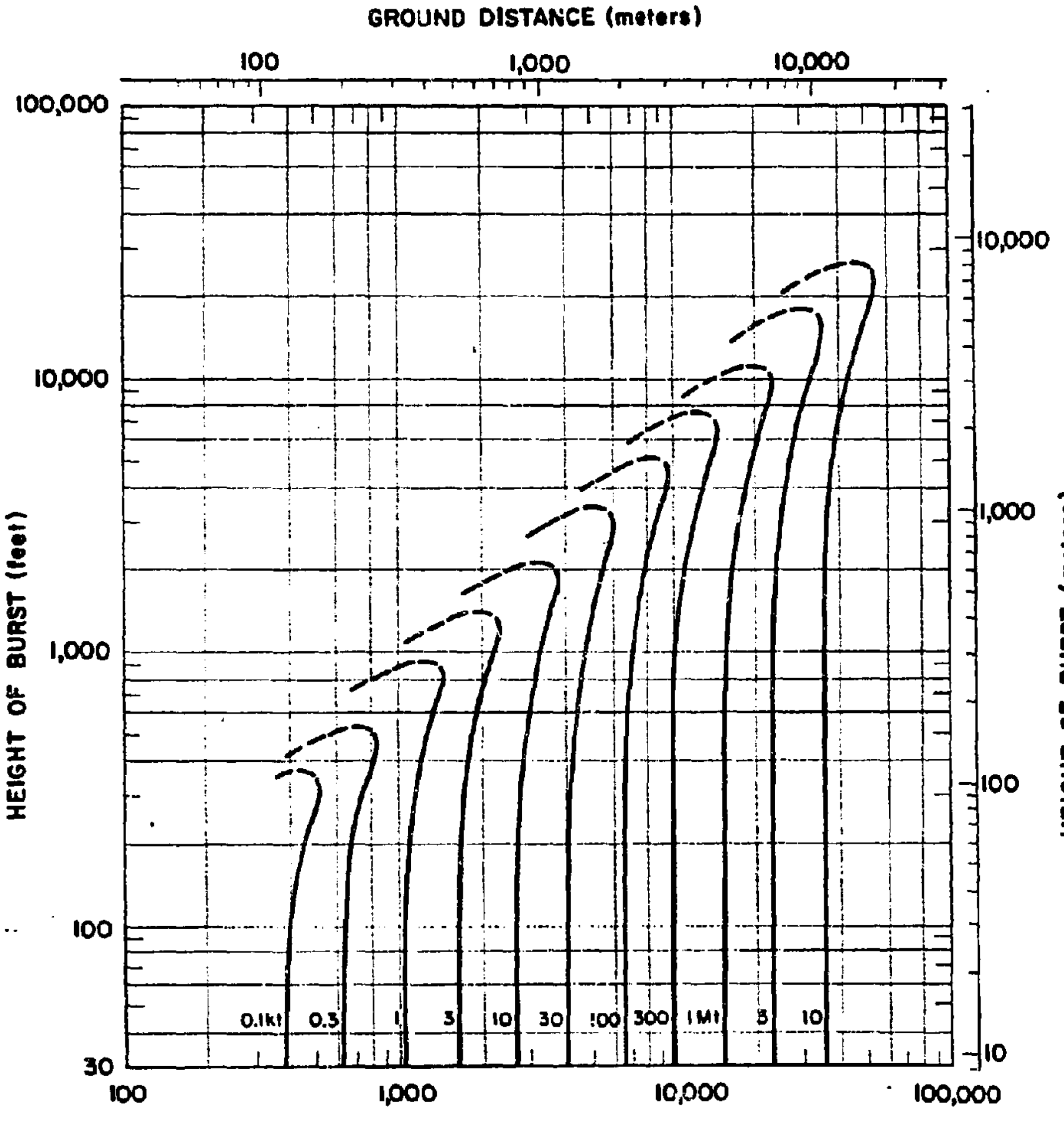

Figure 15-32. [redacted] Total Damage to a Type IVc(d) Forest [redacted]

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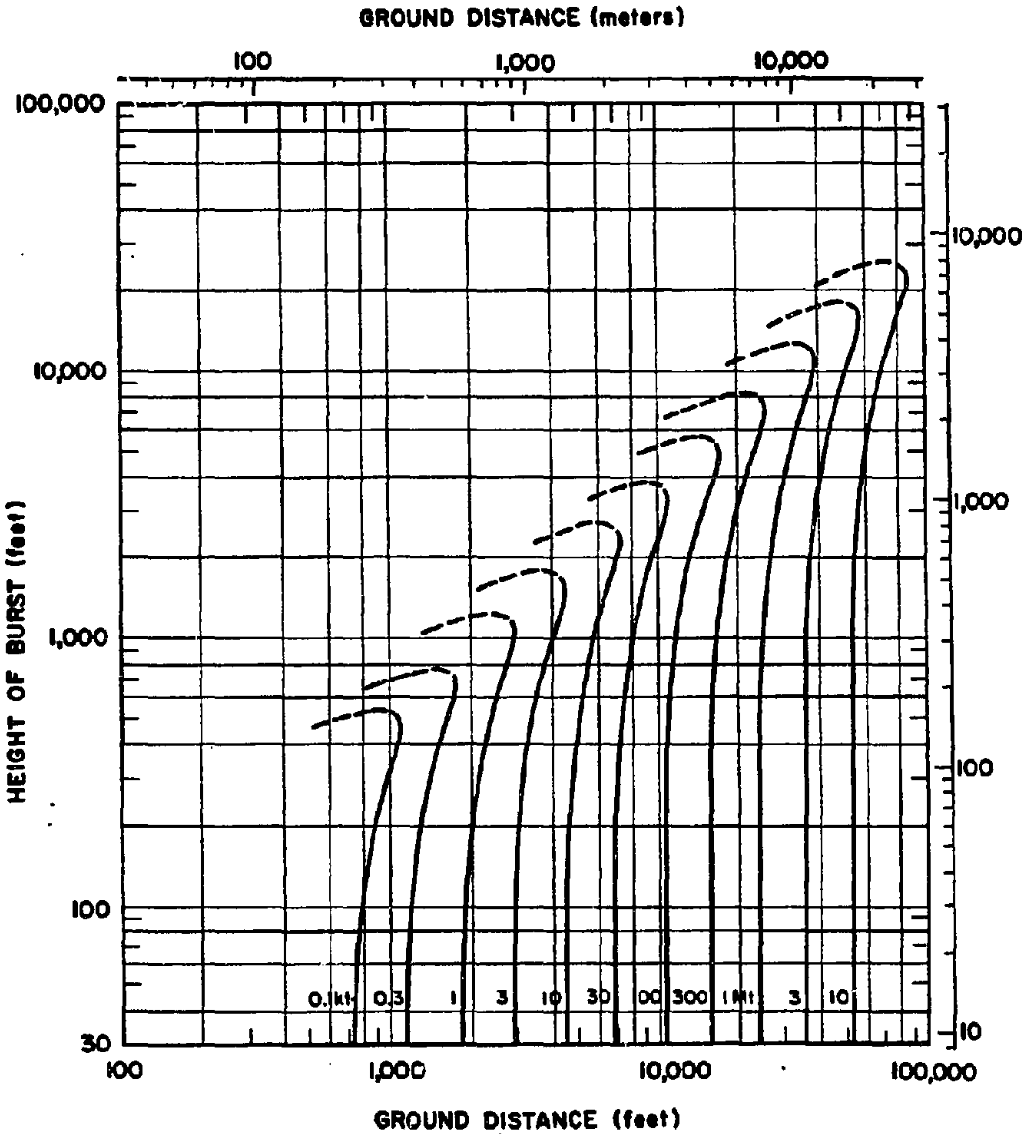

Figure 15-33. [redacted] Moderate Damage to a Type IVd Forest [redacted]

[redacted]

[redacted]

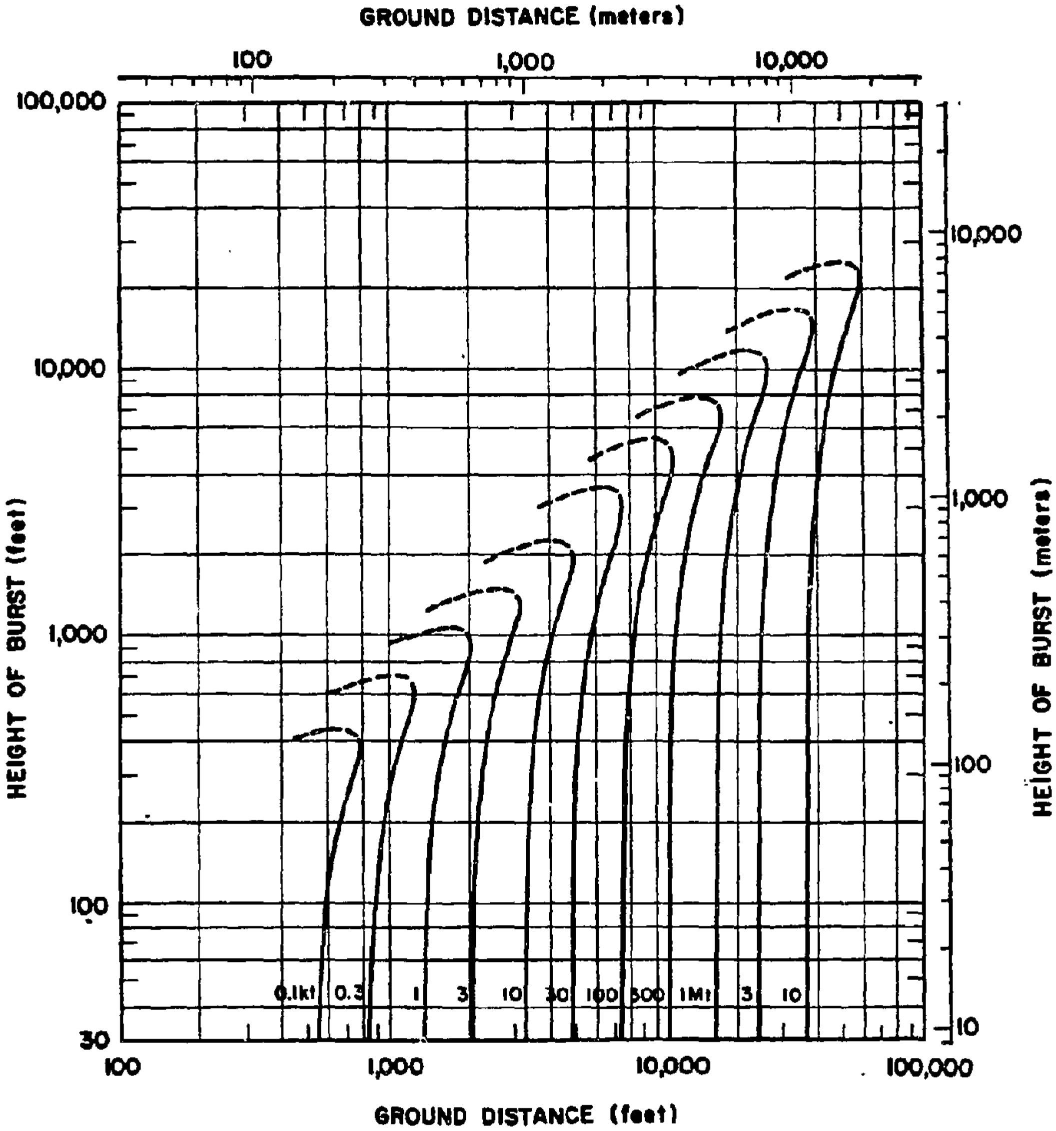

Figure 15-34. [redacted] Total Damage to a Type IVd Forest [redacted]

[redacted]

SECTION II

[redacted] TROOP AND VEHICLE MOVEMENT [redacted]

[redacted] The effects of a nuclear explosion on a forest may have a significant influence on military operations within the region of the forest that is affected by the burst.

[redacted] Two H.E. tests have provided information concerning the character of the region that is damaged and the effect on vehicular and troop movement that the damage will cause. [redacted]

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[redacted] An important difference between the ef-

*[redacted] The information in these tables may be used for yields ≤ 20 kt by determining the ground ranges for equivalent dynamic pressure impulses.

Table 15-3 [redacted] Effects of a 1 kt Weapon Burst at a Height of 270 Feet Over a Rain Forest [redacted]*

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[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

[redacted]

[redacted] fects on broadleaf and coniferous forests is the nature of the [redacted]

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15-3 Blowdown Debris Characteristics [redacted]

[redacted] The impact of the damaged region of a forest on movement is determined by the number and diameter of stems in the path of the vehicles or troops. The variation in these parameters throughout various regions of damage are discussed in the following paragraphs.

[redacted] Data from the two TNT detonations that were mentioned previously are presented in Figures 15-35 and 15-36. Figure 15-35 shows the relation between stem-feet per acre* and ground range for a rain forest and for a coniferous forest. [redacted] The difference [redacted] between the two forests results from the difference in average tree density and tree height of the

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[redacted] See footnote to Table 15-1.

Table 15-4 [redacted] Effects of a 1 kt Surface Burst on a Coniferous Forest [redacted]

[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

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[redacted]

[redacted]

[redacted]

Figure 15-35. [redacted] Stem-ft per Acre Comparison Between a Rain Forest and a Coniferous Forest [redacted]

[redacted] forests. The curve for the rain forest is based on data gathered by observation, while the curve for the coniferous forest is based on calculations, using preshot and postshot tree surveys. Figure 15-36 shows the relation between ground range and average diameter of the debris. [redacted]

[redacted]

[redacted]

[redacted]

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Figure 15-36. [redacted] Average Diameter of Stems Down, Comparison Between a Rain Forest and a Coniferous Forest, 1 kt [redacted]

DNA (b)(1) [redacted] This distance is determined easily from photo reconnaissance, as are the debris zones described in Tables 15-3 and 15-4.

15-4 Vehicle Movement [redacted]

[redacted] The movement rates of various wheeled and tracked vehicles have been measured for both radial and circumferential traverses of various debris zones. Although quantitative data were obtained and can be used, correlations between vehicle movement and debris characteristics are incomplete and are not refined to the point of high reliability. Nevertheless, curves have been constructed that indicate in terms of the debris parameters (number of stem-feet per acre and diameter of debris) when a vehicle will not be able to move. These curves are presented in Figure 15-37 and 15-38 for radial movement from ground zero and circumferential movement, respectively. The general radial orientation of tree stems is significant in terms of movement, because selection of easier routes between stems is possible in some cases of radial movement, while all stems must be crossed in circumferential movement. The shaded areas on the graphs indicate debris characteristics where movement is difficult. The solid line indicates that movement is not possible. For example, from Figure 15-37, for debris characteristics of 10,000 stem-feet per acre with average diameters of 4, 6, and 8 inches, radial movement of wheeled vehicles would be possible, difficult, and not possible, respectively. Curves for wheeled vehicles are fairly well documented with data; however, the curves for the M113 and tank are not, because

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Figure 15-37. [redacted] Debris Characteristics Preventing Radial Movement of Vehicles [redacted]

[redacted]

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Figure 15-38. [redacted] Debris Characteristics Preventing Circumferential Movement of Vehicles [redacted]

[redacted] these vehicles were slowed but not stopped by the debris zones in which they were tested. Tracked vehicles can climb onto the debris and mat it down after a number of passes, with the result that wheeled vehicles might pass, although this technique was not tested.

15-5 Troop Movement [redacted]

[redacted] The effect of blowdown debris on the movement of troops is difficult to present quantitatively. Many factors other than the physical obstacle itself, such as visibility, leadership, size of force, mission, and what the troops are carrying are also influenced by the debris and indirectly affect movement. Movement of troops through a debris zone can be compared with moving through a thick jungle, although radial movement is generally easier than circumferential movement. Branch debris in a broadleaf forest blowdown area adds difficulties, particularly in visibility, that are not as severe in coniferous forest debris. Troop trials were conducted on both TNT detonations previously described.

[redacted] The troop tests conducted in conjunction with the rain forest detonation involved comparisons between preshot and postshot tests of day and night patrols, platoon exercises with a mortar squad, and tests with stretcher parties.

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[redacted]

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[redacted] The night and day patrols were conducted over a route that was about 700 yards long, with one leg from virgin forest to the vicinity of ground zero, then back to the virgin forest on a different bearing.

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[redacted] In the platoon attack trials, control problems were considerably eased in the blowdown area compared to the virgin forest, as a result of increased visibility.

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[redacted] Tests with a loaded two-man stretcher indicated that passage through blowdown debris was very difficult. The stretcher bearers' attention was diverted from the patient as a result of the need to concentrate on locating suitable footing. Consequently, the simulated casualty had a very rough trip and was frequently struck by debris. The conclusion drawn from this trial was that the probability for survival of a casualty with a severe wound would be significantly reduced by transit through blowdown debris. If the casualty survived the carriage, it is almost certain that he would experience a marked degree of secondary shock.

[redacted] Troop trials conducted in the coniferous forest blowdown consisted of radial and circumferential platoon exercises, including a mortar squad, and a simulated casualty-moving test. Some movement rate data that were obtained are shown in Table 15-6.

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Table 15-5 [redacted] Comparison of Radial and Circumferential Movement Rates for Troops in a Rain Forest Blowdown Area, Scaled to a 1 kt Nuclear Explosion [redacted]

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[redacted] An administrative march also was conducted over a radial–circumferential–radial route. The circumferential portion was in the area of maximum blowdown debris. [redacted]

[redacted] A platoon night attack similar to the first circumferential trial described but in the opposite direction was performed. The platoon was organized as three attacking squad columns in line, except for the last 100 yards, where they deployed as a skirmish line. The 2-to-1 ratio in time was observed once again.

[redacted] The moving of a simulated casualty by two- and four-man stretcher bearer teams trav-

Table 15-6 [redacted] Comparison of Circumferential Movement Rates for Troops in a Coniferous Forest Blowdown Area, Scaled to a 1 kt Nuclear Explosion [redacted]

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[redacted] eling circumferentially also was tested. Results were essentially the same as those from the rain forest trials.

15-6 Predicting Effects on Movement [redacted]

[redacted] The results of the tests conducted after the two TNT detonations, together with the forest descriptions in Section I and Table 15-1, and the forest damage definitions in paragraph 15-2, have been combined in Table 15-7 for use with Table 15-2 and Figures 15-1 through 15-34 to predict the ground distances at which movement will be affected to various degrees. The forest damage levels in Table 15-7 are restricted to Severe and Total, because Light and Moderate damage to forests have little influence on movement, except as a result of changes in visibility. Example problems will illustrate the use of Table 15-7 and will outline the limitations of the information presented.

Table 15-7 [redacted] Influence of Forest Damage on the Movement of Troops and Vehicles [redacted]

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[redacted]

Problem 15-2 Calculation of the Distance at Which Movement Will Be Impaired

[redacted] Table 15-7 together with Table 15-2 and Figures 15-1 through 15-34 provide the information necessary to estimate the area within which movement will be affected to various degrees as a result of tree blowdown. The information contained in these tables and figures allows determination of the affected area for movement of troops or vehicles as a function of weapon yield and forest stand type.

[redacted] *Example* [redacted]

Given: A 2-[redacted] burst at 1,640 feet above a Type III forest stand.

Find: Will wheeled vehicles be stopped by the forest damage and at what maximum range?

[redacted]

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[redacted]

Problem 15-3 Estimation of Movement Difficulty

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[redacted] Therefore, it is possible to perform some evaluation of a forest using Figures 15-37 and 15-38 together with the forest characteristics. The forest characteristics required are tree density in trees per acre, average forest height in feet, average girth at breast height of the forest trees in either inches or centimeters, and tree type. The following parameters can then be determined:

Maximum Debris = (Forest density) (average height)

Average Debris Diameter in inches; girth, g, given in centimeters

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[redacted]

Average Debris [redacted]; girth, g, in inches

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[redacted]

With these two parameters, the potential obstacle of a forest can be estimated.

Example [redacted]

Given: A coniferous forest with a density of 200 trees per acre and average height of 50 feet. Girth at breast height averages 33 inches.

Find: What obstacle could be formed if the forest were damaged by a nuclear burst.

[redacted]

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[redacted]

SECTION III

[redacted] THERMAL RADIATION [redacted]

[redacted] Under certain conditions, a nuclear weapon that is exploded over a forest or wildland area may cause fires. During the fire season, even when the burning potential (a measure of probable fire aggressiveness) is low, fires may spread. If fires are started in regions of sufficient fuel density when the burning potential is dangerously high, complete evacuation of personnel and equipment may be necessary. Organized control of the spread of the fire is virtually impossible until changes in weather or fuel availability reduce the burning potential.

15-7 Ignitions [redacted]

[redacted] Wildland fuels are typically a mixture of thin and heavy fuel components. Often, the thinner fuels will establish the limiting radiant exposure that will be required to start fires in the mixture.

[redacted] When fuels are dry, ignitions that have a reasonable chance of surviving the subsequent blast effects and of initiating fires that can represent a hazard to military personnel in the forest can be expected at quite low levels of radiant exposure. For example, broadleaf and coniferous litter (mixtures of fine grass, broken leaves and duff, and thin translucent broadleaf leaves) can be ignited by exposures of 2 to 3 cal/cm^2 from 1 kt low-altitude air burst, and heavier leaves (dead grass, conifer needles, and fallen, nearly opaque broadleaf leaves) can be ignited by exposures between 3 and 4 cal/cm^2, which correspond to distances at which 2 to 3 psi peak overpressures might occur, provided the full free-field radiant exposure falls on these fuels. As will be discussed subsequently, the likelihood of the full free-field exposure reaching these fuels in a forest area is quite low. Radiant exposure values required to ignite materials increase with moisture content and will be larger for the longer duration pulses of larger-yield weapons. The increase caused by moisture being absorbed from the air at high relative humidities ordinarily will not be more than a factor of 2 to 3. Wet or green leaves, however, may be impossible to ignite and, if ignited, they will not participate in the development of a persistent fire. The live foliage of conifers and many shrubs ignited by fire in associated dead fuel, however, burn vigorously and would add significantly to the intensity of spreading fire. This foliage is often the significant factor determining whether or not a crown fire develops.

15-8 Kindling Fuels [redacted]

[redacted] The majority of thin wildland fuels that serve as kindling material are typed into four classes as shown in Table 15-8. These classes correspond to different minimum exposures required for ignition. Since ignition generally occurs on surfaces that are most exposed to the atmosphere, ignition exposures are a function of relative humidity as shown in Figure 15-39. Fires may be blown out by the blast wave, depending on the time interval between ignition and arrival of the shock. Blowout is not expected to occur

Table 15-8 [redacted] Classes of Thin Wildland Kindling Fuels (Arranged in Order of Decreasing Flammability) [redacted]

Class	Description
I	Broadleaf and coniferous litter—mixture of fine grass, broken leaves and duff, and thin translucent broadleaf leaves.
II	Hardwood and softwood punk in various stages of decay.
III	Cured or dead grass.
IV	Conifer needles and thick, nearly opaque broadleaf leaves.

[redacted]

[redacted]

[redacted] in overpressure regions below 5 psi or when the fuels are fully exposed. When fires are not blown out, they generally increase in intensity as a result of the blast wind.

[redacted]

[redacted]

Problem 15-4 Calculation of the Requirements for Wildland Kindling Fuel Ignition

[redacted] The curves of Figure 15-39 show the maximum radiant exposure as a function of relative humidity for ignition of wildland kindling fuels described in Table 15-8. The radiant exposures shown in Figure 15-39 apply to a 1 kiloton nuclear explosion.

[redacted] *Scaling.* For yields other than 1 kt, scale as follows:

$$\frac{Q}{Q_1} = W^{1/8}$$

where Q_1 is the radiant exposure for ignition of a particular class of wildland kindling fuel for 1 kt, and Q is the corresponding exposure for a yield of W kt.

[redacted] *Example* [redacted]

Given: A 40 kt weapon burst over a Class III wildland fuel when the relative humidity is 75 percent.

Find: The minimum radiant exposure required to ignite the fuel.

Solution: From Figure 15-39, the minimum radiant exposure for ignition of a Class III wildland fuel by a 1 kt explosion when the relative humidity is 75 percent is 4 cal/cm^2.

Answer: The corresponding exposure for 40 kt is

$$Q = Q_1 W^{1/8} = 4 \times (40)^{1/8} = 6.3 \text{ cal/cm}^2.$$

Reliability: Based upon observed results of limited full-scale tests and extensive laboratory experiments. The results are not considered reliable in the megaton range.

Related Material: See paragraphs 15-7, 15-8. For forest areas, see paragraphs 15-9 through 15-10. For determination of distances corresponding to a particular radiant exposure, see Chapter 3.

[redacted]

[redacted]

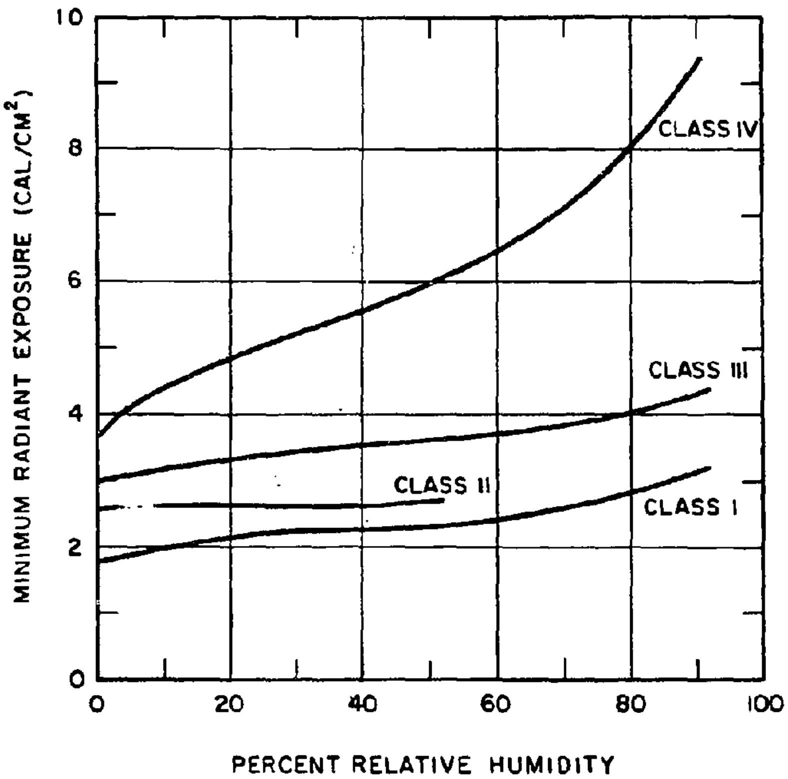

Figure 15-39. [redacted] Minimum Radiant Exposures of Wildland Kindling Fuels by a 1 Kiloton Explosion [redacted]

[redacted]

[redacted]

15-9 Thermal Radiation on Forests [redacted]

[redacted] Probably the largest uncertainty associated with thermal radiation on forested areas arises from a lack of information about the transmission of the radiation through the foliage and other obscuring features of forest stands for high-yield air bursts.

[redacted] Methods for approximating the fraction of the free-field thermal radiation exposure that is transmitted by the forest environment will be considered here. The methods for calculating the free-field exposure are discussed in Chapter 3.

[redacted] Both from the point of view of causing injury to exposed personnel and of starting fires, the primary interest is in assessing the exposure of the forest floor to thermal radiation from the nuclear fireball. The foliage making up the crowns of the trees, while it has a high probability of being exposed to the full free-field radiation environment from air bursts and may be severely dessicated, thermally (even explosively) decomposed, and, at high enough flux levels, flash ignited, is not likely to contribute to subsequent sustained fires. It may, however, materially reduce the exposure of the forest floor by generating quantities of smoke and steam as well as by direct shading.

[redacted] Neglecting these thermally-induced, self-protective screening effects (noting that "scattering in" may effectively offset "scattering out"), an approximation to attenuation by trees and associated vegetation may be obtained by assuming that the attenuation is proportional to the extent of coverage of the field of view of the fireball by the elements of the forest canopy, i.e., that the exposure of any spot on the ground is roughly proportional to the apparent area of the fireball seen by that spot. Hence, height of burst and yield are important geometrical parameters that must be considered.* [redacted]

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[redacted] Size of openings and tree height are other important determinants of the susceptibility of a forest to ignition from an air burst. This indicates the need for on-the-ground or from-the-air appraisal of forests and presumed explosion situations. This can be done with reasonable accuracy and much more rapidly from aerial observation or photographs than from surface measurements.

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*[redacted] Note that this assumes the source of thermal radiation to be above the tree tops. It will be seen in the subsequent discussion that thermal transmission is negligibly small for the low line-of-sight angles corresponding to burst heights less than tree heights, except perhaps for the short transmission paths that accompany bursts in the extreme low-end of the range of yields. Significant thermal exposures will never occur from these weapons, even in a sparsely vegetated forest environment, at distances corresponding to peak overpressures of 10 psi and less, because free-field exposure at these distances are only about 4 cal/cm^2 and less.

[redacted]

[redacted]

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[redacted]

[redacted]

[redacted] The "standard Northern European forest" represents a composite of the characteristics of the forests of northern Europe obtained by averaging the features of 10 different forest stands chosen as representative of type (pine woods, spruce and deciduous forests, and mixtures of these) and tree density (range of about 200 to 1,000 trees/acre).

Table 15-9 [redacted] "Standard Northern European Forest" Data† [redacted]

[redacted]

†[redacted] Sites were chosen on flat terrain in Northern Europe having uniform density distributions and generally uniform tree height (not more than 15% variation for not less than 90% of the trees in the stand). This uniformity is typical of the managed forests of Europe along with a general absence of undergrowth. These characteristics are not common to unmanaged (natural) forests. There is no reason to expect that information derived from these studies are in any way applicable to tropical hardwood forests.

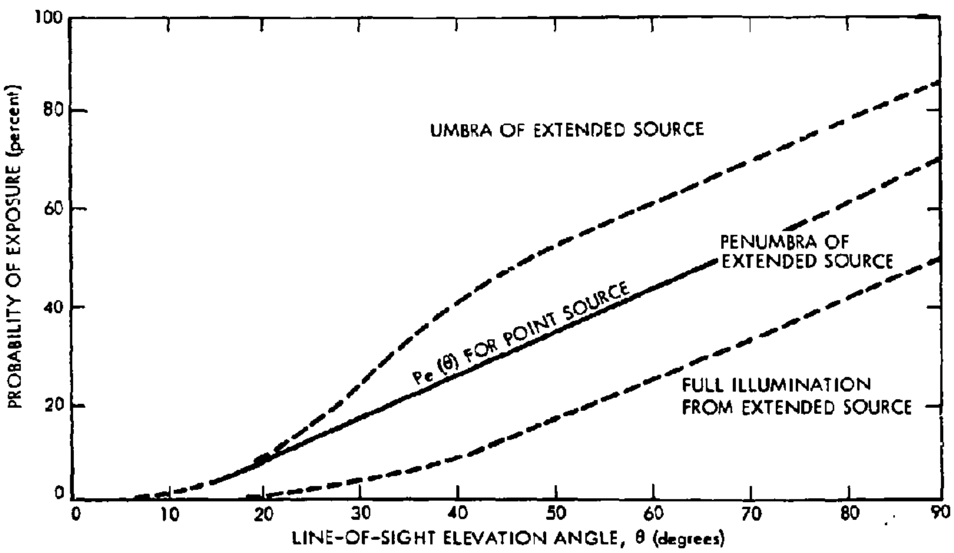

Figure 15-40. [redacted] Probability of Exposure of the Forest Floor ("Standard Northern European Forest") as a Function of Elevation Angle; Examples of a Point Source and a Spherical Source Subtending an Angle of 10 Degrees [redacted]

[redacted]

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[redacted] Obviously $Pe(\theta)$ functions, as illustrated by the "standard Northern European forest" in Figure 15-40, must depend on forest characteristics, notably tree density, with increased dispersion expected toward the larger angles of elevation. The data presently available do not reflect the degree of dispersion nor its dependence on forest characteristics adequately. Some idea of dispersion with tree density can be obtained from Figure 15-41, which displays the range of available results.

[redacted] Although the current data base is quite poor, particularly as it applies to unmanaged forests and tropical or temperate-broad-leaf forests, it can be inferred that direct thermal effects in the forest environment do not contribute substantially to damage and casualties at distances where blast effects are not extreme, except, perhaps, in the least densely populated stands (less than 50 to 100 trees per acre). For most tactical situations where survival of blast effects can be expected, radiant exposures would be much less than half the free field over most of the floor of forests having densities of a few hundred or more trees per acre, and probabilities of exposure to the full free-field level would be negligibly small.

15-10 Forest Fire Ignition and Spread [redacted]

[redacted] Under certain conditions, the explosion of a nuclear weapon over a forest or wildland area may cause fires. During the fire season, even when the burning potential is low, fires may spread. If fires are started in regions of high-fuel density when the fire potential is high, complete evacuation of personnel and equipment may be necessary. Organized control may be impossible until changes occur in the weather or the fire runs out of fuel.

[redacted] An important exception to kindling fuel exposure to the full free-field radiant environment occurs in unmanaged forests of the temperate and cold regions. Many of these forests contain an abundance of dead and frequently punky

[redacted]

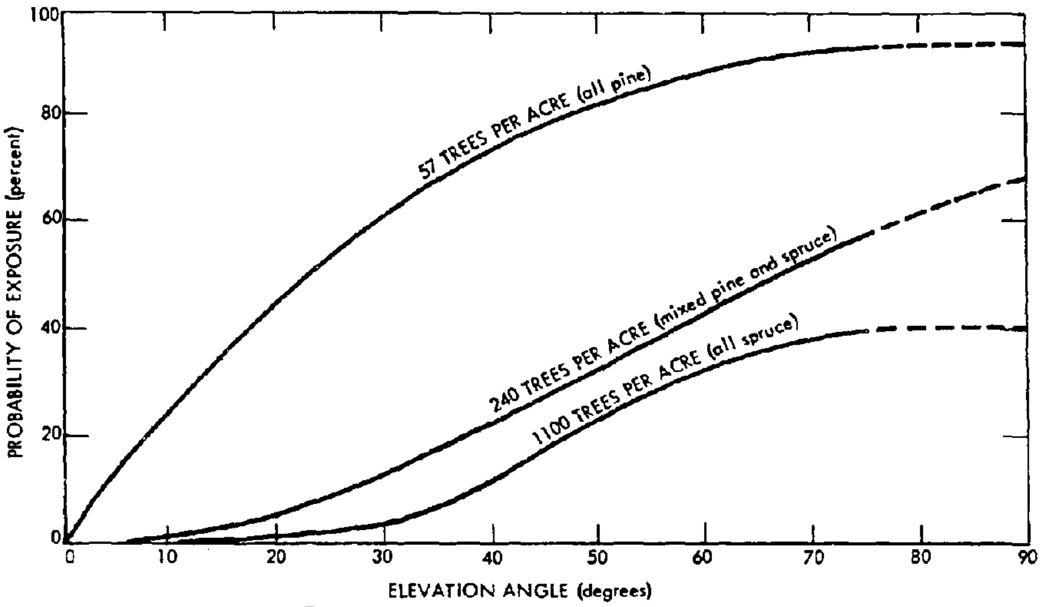

Figure 15-41. [redacted] Probability of Exposure of Forest Floor for Different Levels of Tree Density [redacted]

[redacted] wood exposed at or above the general canopy level. Of the common forest fuels, wood punk is probably the most susceptible to ignition by the thermal pulse. Moreover, since ignition is by charring or glowing combustion, these fuels are less susceptible to extinction by the blast wave than those that ignite with flame. These punky fuels, often easily detached from the parent tree, may be carried downwind for considerable distances and dropped to the forest floor as live embers. More rapid decomposition of dead wood makes this a less likely phenomenon in the moist tropics.

[redacted] As mentioned previously, the blast wave may extinguish fires at substantial overpressures, but the current state of the art does not permit quantitative evaluation of this phenomenon. On the other hand, at close-in distances where the blast wave arrives early during the thermal pulse (at times less than about 8 t_{max}) sufficient radiant exposure may follow the blast wave to re-ignite fuels and/or to ignite blast-created tinder.

[redacted] Current interpretations of the qualitative effects of blast on the persistence of incipient fires are based largely on experiments where kindling fuels were anchored in place. Had these fuels been free to move with the blast, many of them would have been translated for considerable distances as effective firebrands. Fire spread following ignitions by these brands would be influenced significantly by the return flow through the negative blast phase of the blast wave.

[redacted] The high degree of shading by tree crowns and stems for detonations at or below the canopy level often may be offset by scattering of burning debris ignited within the fireball. Many forest types contain large quantities of dead and rotten wood on and above the ground surface. If these materials are in flammable condition they may be expected to travel outward to the approximate limits of tree blowdown and provide plentiful ignition sources. Initial spread of fire from these

[redacted]

Table 15-10 [redacted] Condition of Wildland Fuels During Fire Season [redacted]

Fuel Type	Amount and Density of Fuel Required to Constitute a Fire Hazard	Condition During Fire Season
Grass or heath: Grassland; dry bracken ferns and other seasonal plants; dry regrowth in previously burned areas.	Uniform grass cover one-half ton or more per acre.	Vegetation nearly cured or dead.
Evergreen brush: Perennial evergreen shrubs and brush; chapparal; young evergreen growth.	75 percent or more covered.	15-25 percent by weight of leaves and associated twigs dead.
Deciduous broadleaf forest: Forest predominantly of trees such as oak, birch, maple, leaves of which die and fall every year.	Ground covered with more or less continuous layer of dead leaves.	Leaves off trees; ground vegetation dead or nonexistent.
Coniferous forest: Forest of evergreen pines, firs, spruces, etc.; generally the family of needle bearing trees.	Ground covered with more or less continuous layer of dead needles and twigs.	Needles and twigs dry enough to break easily when bent. Grass and other ground vegetation, if present, curing or dead.

[redacted] sources would also respond to the inflow during the negative phase of the blast wave. Later behavior would depend on the degree of involvement of blowdown debris and the ambient weather.

[redacted] Times of the year during which the fire hazard is apt to be high are referred to as fire seasons. These are determined principally by the annual rainfall–temperature pattern and the amount and kinds of vegetation associated with it. Fire seasons vary widely from place to place throughout the world. Conditions associated with fire seasons in some typical wildland fuels are shown in Table 15–10. The more difficult problem is that of obtaining and systematically appraising local forest flammability data within a fire season on a day-to-day basis for fire spread predictions. No one formula will fit all situations.

[redacted] The main factors, aside from the fuels, that determine the fire hazard are: the nature of the terrain; the wind speed close to the ground; the relative humidity; and the precipitation history. Fuels seldom burn vigorously, regardless of wind conditions, when fuel moisture content exceeds about 16 percent. This corresponds to an equilibrium moisture content for a condition of 80 percent relative humidity. Rainfall of only a fraction of an inch will render most fuels temporarily nonflammable and may extinguish fires in thin fuels. The time required to restore the fire-danger condition may vary from hours to days depending on weather and soil conditions. Surface fuels in the interior of timber stands are exposed to reduced wind velocities; generally, these fuels retain their moisture as a result of

Table 15-11 [redacted] Criteria of "No-Spread" of Fires [redacted]

Fuel Type	Criteria
All forest fuels	Over 1 inch of snow on the ground at the nearest weather stations.
Grass	Relative humidity above 80 percent.
Brush or hardwoods	0.1 inch of precipitation or more within the past 7 days and: Wind 0-3 mph; relative humidity 60 percent or higher, or Wind 4-10 mph; relative humidity 75 percent or higher, or Wind 11-25 mph; relative humidity 85 percent or higher.
Conifer timber	1. One day or less since at least 0.25 inch of precipitation and: Wind 0-3 mph; relative humidity 50 percent higher, or Wind 4-10 mph; relative humidity 75 percent higher, or Wind 11-25 mph; relative humidity 85 percent or higher. 2. Two to three days since at least 0.25 inch of precipitation and: Wind 0-3 mph; relative humidity 60 percent or higher, or Wind 4-10 mph; relative humidity 80 percent or higher, or Wind 11-25 mph; relative humidity 90 percent or higher. 3. Four to five days since at least 0.25 inch of precipitation and wind 0-3 mph; relative humidity 80 percent or higher. 4. Six to seven days since at least 0.25 inch of precipitation and wind 0-3 mph; relative humidity 90 percent or higher.

[redacted]

shielding from the wind and shading from sunlight by the canopy. The spread or no-spread criteria are summarized in Table 15-11. This table lists the conditions under which fire would not be expected to spread.

[redacted] The criteria of Table 15-11 have been compared to the records of 4,378 wildland fires. Of the fires for which "no spread" would be predicted, 97.8 percent did not spread; only 40 percent of the fires that were predicted to spread actually did spread (at a rate of 0.005 mph or faster). This failure to spread often may be attributable to lack of fuel continuity around the point of origin.

[redacted] The criteria of Table 15-11 are considered to be reliable for American forests and suitably conservative to assure a low level of hazard to friendly forces. On the other hand, the criteria are probably not overly conservative to predict conditions for which enemy forces may be denied forested areas because of fire whenever the local weather history and conditions at the time of

[redacted]

Table 15-12 [redacted] Fire-Out Criteria [redacted]

Fuel Type	Criteria
Grass	"No-spread" conditions, or measurable precipitation.
Brush or hardwoods	0.1 inch of precipitation or more, or "no-spread" conditions for the next 12-hour period.
Conifer timber	1. 0.5 inch of precipitation or more; 2. 0.25 to 0.5 inch of precipitation and "no-spread" conditions for the following two 12-hour periods; 3. "No-spread" conditions for eight consecutive 12-hour periods and measurable precipitation during any two 12-hour periods; 4. "No-spread" conditions for 14 consecutive 12-hour periods.

[redacted]

detonation are known reliably, or whenever the initial fire is expected to be of substantial size.

[redacted] Weather conditions are subject to change, sometimes unpredictably, and fires that have been spreading may stop or go out. Conversely, fires that have not been spreading (other than on the microscale necessary to keep them dormantly alive) may flare up quite suddenly and spread rapidly as a result of a change in the weather. Whenever this threat of weather change cannot be tolerated, it is necessary to choose conditions for the employment of nuclear weapons so that dormant fires will not persist for times that are long compared to reliable weather-forecast periods. The "fire-out" criteria in Table 15-12 provide guidelines for this purpose. These criteria are derived from opinions of experienced fire personnel and should not, therefore, be considered to be as reliable as the "no-spread" criteria.

[redacted] Under identical weather conditions, concentrations of heavy fuels are more hazardous than thin fuels, even though they tend to reduce wind speeds locally and do not respond as rapidly to changes in relative humidity. This results from the fact that trees and heavy limbs on the forest floor may be ignited by an otherwise non-hazardous surface fire, and when heavy fuels are present near the borders of standing timber, the fire may travel into the tree crowns and spread from top to top even though ground fuel concentrations are low. Coniferous trees are most susceptible to crown fires. Hardwoods (deciduous trees) rarely, if ever, exhibit a true crown fire.

[redacted] Considerable information exists concerning rates of fire spread in American forests from historical records of major forest fires. Rates of spread rarely exceed 1 mile per hour except for brief periods of time during extreme burning conditions. Crown fires are capable of spreading at rapid rates, exceeding the rates of progress by men on foot attempting to out-run them. The high rate of progress of fire through crowns of trees probably results from the unimpeded wind-flow velocities above the forest canopy.

[redacted] Because of their potentially rapid rates of spread, crown fires represent a much higher level of hazard to personnel in forests than surface fires. Accordingly, it is desirable to be able to predict the occurrence of crown fires. Unfortunately, only qualitative criteria are available.

[redacted]

Table 15-13 [redacted] Burning Durations by Fuel Type [redacted]

	Violent Burning		Residual Burning		
Fuel Type	Time (min)	Energy Release (percent)	Time (min)	Energy Release (percent)	Total Burning Time
Grass	1.5	90	0.5	10	30 min
Light Brush (12 tons/acre)	2.	60	6.	40	16 hr
Medium Brush (25 tons/acre)	6.	50	24.	50	36 hr
Heavy Brush (40 tons/acre)	10.	40	70.	60	72 hr
Timber	24.	17	157.	83	7 days

[redacted] Surface fires exhibit brief "runs" at high speeds (a few miles per hour for several minutes, and a large fraction of a mile per hour for up to an hour or more), but average speeds over long periods of time range generally from 0.01 mile per hour to 0.5 mile per hour, with the most frequently noted values in the range of 0.1 to 0.5 mile per hour for 6- to 11-hour periods and in the range of 0.01 to 0.1 mile per hour for durations of 12 hours and more. These values are for American forests and should not be expected for managed forests (such as those of Europe) or tropical hardwood forests (such as those of some areas of Southeast Asia).

[redacted] An additional factor that affects the hazard of fire to military personnel and equipment is the burning duration of forest fuels. Examples of burning durations for fuels that are typical of American wildlands are summarized in Table 15-13.

[redacted] Table 15-13 refers to natural fuels in their undisturbed states. Experience shows that the highest fire intensities and fuel consumptions occur in the areas of greatest fuel accumulation. This fact has two implications with respect to nuclear detonations: if burning conditions are favorable, incipient fires from the thermal pulse falling on areas covered with a large amount of blast debris may build up rapidly; the blast debris accumulation may subsequently desiccate sufficiently to be a prime target for ignition by any means, either friendly or enemy.

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